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IDA PAPER P-2982

THE VALUE OF SIMULATION FOR TRAINING

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Christine Youngblut

September 1994

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Only the authors, rather than those who tried to help them, are responsible for the views expressed in this report.

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SUMMARY

PURPOSE

The purpose of this study is to examine the utility of simulation for training at the individual, unit, and joint force levels of readiness and to propose guidelines for the development of new technology relevant to training, particularly in the area of advanced distributed simulation.

BACKGROUND

The use of simulation for training at all levels, from firing a rifle in a school to a large-scale, joint exercise in the field, is a widely accepted practice. Simulations are used routinely in such cases as the initial familiarization of novices in the operation and maintenance of simple equipment (e.g., radio or compass), or complex equipment (e.g., aircraft or nuclear control station), or in handling potentially catastrophic events (e.g., failure of an engine in an aircraft, or an over-heating boiler or a fire on a ship). Questions about the utility of simulation can (and should) arise as to the ability of a simulator to represent the operation of the actual equipment in its real world environment or of a combat model to represent actual combat (i.e., fidelity of the simulation); the specific tasks for which a simulator can offer effective training (e.g., whole or part training, maintenance or operation); the ability to use skills learned in a simulator on the actual equipment in its real-world environment (called "transfer"); the relative costs and effectiveness of using simulators for training as compared to those of using the actual equipment (simulators tend to be less expensive); and the optimum combination of the use of simulators and actual equipment for most effective training at least overall cost (this should be the bottom line). In addition, military personnel should be concerned when use of a simulator is advocated to save costs and funds for OPTEMPO (operating tempo for ships, aircraft, and vehicles), that is, training and exercises with actual combat equipment are to be cut.

Up to about 15 years ago, the term "simulation" referred almost entirely to devices used for training individuals to perform some of the tasks associated with their jobs as pilots, navigators, maintainers, repairers, firemen, communicators, and the like. Today, advances in high-speed, wide bandwidth communication networks and high-performance

computers have made possible the use of distributed interactive simulation for collective training at all levels, including joint training and readiness. This new capability supports large-scale combat training exercises, both at Service and joint levels, precisely at a time when funds for field exercises are being reduced because of cost and environmental factors. It is important to point out that the development of distributed interactive simulation for training will also improve the contributions that this technology can make to component and joint readiness, test and evaluation, mission preparation and rehearsal, and the development and evaluation of tactics and doctrine.

In the treatment that follows, we consider four types of simulation used for training: stand-alone simulators, networked interactive simulation (virtual simulation), exercises on instrumented ranges (live simulation) and computer-based combat models (constructive simulation). We consider two types of training—individual and collective training, including joint training—and two places where military training occurs—institutions (schools) and operating units. Data on the effectiveness and cost of training by type of simulation, and by place of training vary in their completeness and quality.

FINDINGS

This paper considers issues with respect to research and development, procurement and utilization that are central to the development of policy concerning the use of simulation for military training. Findings concern budgets related to simulation and training, the cost and effectiveness of simulation, experience of the Services with simulation, distributed interactive simulation, and the technologies relevant to simulation and training.

Budgets Related to Simulation and Training

Budget data on the costs of simulation and training are not reported regularly in the Department of Defense. This means that our ability to discern trends in costs of different types of training (e.g., individual or collective training), or to compare the costs of training at a school to training in an operational unit, or to direct research and development towards areas of highest pay-off for training effectiveness and cost is seriously limited. The costs of OPTEMPO are not well known; in fact, we found two different estimates of the costs of OPTEMPO that differ by a factor of 2.3. In this report, data from various sources are compiled to estimate what some of these costs are; some of the data are highly reliable, while some lack clear definition as to what cost elements may or may not be included. Our findings are summarized in Figure S-1 (and are discussed more fully in Chapter II).

Type of Expenditure	Amount[1]	Period	Source
RDT&E			
Simulators for weapon systems	$0.336	FY91–97	Frost & Sullivan (1993)[2]
Technology			
Training equipment	0.101	FY94	MATRIS (1993)[3]
Training methods	0.038	FY94	MATRIS (1993)[3]
Modeling and simulation			
Joint commands	0.019	FY 91–92	IG (1993)[4]
DMSO	0.073	FY 93–94	DMSO (1994)[5]
ARPA	0.103	FY 92–97	ARPA (1993)[6]
Initial investment			
Procurement of simulators		FY 91–97	Frost & Sullivan (1993)
Aviation $ 0.800			
Non-system devices 0.243			
All others 0.057			
	1.100		
Models and simulations	NA		
Military Construction	NA		
Operating and Support			
Individual training in institutions	14.4	FY94	MMTR (1993)[7]
Individual training in units	NA		
Collective training in institutions	NA		
Collective training in units	12.7	FY93	LMI (1993)[8]
OPTEMPO	9.4 21.4	FY93 FY91	LMI (1993) Angier et al. (1992)[9]
Joint exercises	0.425	FY 94	Briefing material
Simulator maintenance	0.369	FY 91–97	Frost & Sullivan (1993)

1 Amount, in billions, for year cited or average of years noted.
2 Frost & Sullivan (1993)
3 Manpower and Training Research Information System (1993)
4 Inspector General (1993)
5 Defense Modeling and Simulation Office (1994)
6 Advanced Research Projects Agency (1993)
7 Military Manpower Training Report, FY 94 (1993)
8 Logistics Management Institute (1993)
9 Angier, Alluisi, and Horowitz (1992)
NA: Not Available

Figure S-1. Estimated Annual Expenditures for Training and Simulation in Terms of RDT&E, Initial Investment, and Operating and Support of Training

Individual training occurs at schools and cost $14.4 billion in FY 94. Collective training occurs in operational units but its costs are not reported regularly; it was estimated to cost $12.7 billion in FY 93. Two estimates were found for expenditures for OPTEMPO (fuel, consumables, repairs and maintenance for flying hours, steaming days, and vehicle miles): $9.4 billion (FY 1993, LMI) and $21.4 billion (FY 1991, Angier, Alluisi and Horowitz). The larger estimate includes costs for repair and depot maintenance not included in the smaller estimate; except for this item, we were not able to resolve the basis for these widely different estimates. The fact that two FFRDCs developed such different estimates for the cost of OPTEMPO illustrates the importance of having reliable and regular estimates of the costs associated with various aspects of simulation and training.

The procurement of simulators for training costs about $1.1 billion per year (average of FY 91–97); RDT&E and support of simulators cost an additional $0.5 and $0.4 billion, respectively. The most expensive simulators are for aviation; they cost about $0.8 billion per year to procure (73 percent of the costs of simulators for all types of weapon systems); non-system training devices cost $0.2 billion (22 percent); simulators for all other types of weapons cost $0.6 billion per year (5 percent).

Expenditures for RDT&E on simulators and training equipment average about $0.4 billion per year, training methods about $0.04 billion, and modeling and simulation (for DMSO, ARPA, and the Joint commands) about $0.19 billion per year.

Significant issues in the cost of training are who is trained and where training occurs. "Who is trained" refers to individual is opposed to collective training; "where training occurs" refers to institutions (i.e., schools) or operational units. The problem in ascertaining the cost of each type of training at various places (and the related issue of evaluating their cost and effectiveness) arises because, except for individual training at institutions, there is no regular or consistent report that identifies the cost of all other types of training. Our estimates of what these costs are were compiled from a variety of sources, as shown in Figure S-2. The costs of RDT&E and initial investment are not included in this figure; we were not able to find any usable data on the costs of collective training in institutions or of individual training in units. We estimate individual training in institutions cost $14.4 billion in FY 94; this is a reliable figure. Other costs, as estimated by a variety of sources, are as follows: collective training in units cost $12.7 billion in FY 1993; OPTEMPO cost either $9.4 or $21.4 billion (FY 91), according to two different estimates; and Joint exercises cost about $0.425 billion (FY 1994).

Where Training Occurs

Who is trained	Institution	Unit
Individual	By service, FY 94[1] Army $5.4 B Navy 4.5 Marine Corps 1.3 Air Force 3.2 14.4 By type, FY 94[1] Recruit $1.2 B Officer acquisition .5 Specialized skill 4.1 Flight 2.2 Professional development .9 OSUT (Army)[7] .3 14.4	Not available: Individual (on-the-job) training in units for those trained only on the job, job familiarization for those trained at schools, and training for those assigned jobs that do not match their MOS[6]
Collective	Army Combat Training Centers, FY 95 .5 B[5] Other data not available	Unit training $12.7 FY 93[2] OPTEMPO 9.4 FY 93[2] 21.4 FY 91[3] Joint exercises 0.425 FY 94[4]

1 MMTR (1993).
2 LMI (1993).
3 Angier, Alluisi, and Horowitz (1992).
4 Briefing Estimate.
5 AUSA (1994); about one-third of this total is for transport to and from the training center (Fig. II-16).
6 CBO (1994) estimates 6-10 percent mismatch between job and MOS in the Army, FY 1993 (p. 32).
7 OSUT: Army One-Station Unit Training; combines Recruit and Specialized skill training.

Figure S-2. Estimated Annual Expenditures for Training, by Type of Training and Where Training Occurs (does not include RDT&E and initial investment)

Cost and Effectiveness of Simulation

Evaluations of the cost and effectiveness of simulation for training are based almost exclusively on the use of flight and maintenance simulators and of computer-based instruction for initial individual training at institutions. The cost and effectiveness of

simulation for more advanced individual training in units or for collective training at institutions or in units for component or joint training has not received much attention. The available findings show that simulators are cost-effective for initial flight and maintenance training in institutions: they train as well as does actual equipment and cost less to procure and use. This finding applies also to computer-based instruction as compared to conventional classroom instruction. Simulators are a good investment. The cost of their procurement can be amortized in periods of one to four years. However, optimum combinations for the use of simulators and actual equipment for various types of training have not been studied; nor have such critical issues as the rates of learning and forgetting, which are basic to determining how much and when simulators or actual equipment are best used for initial and refresher training. The decision to use new simulators on the basis of equal effectiveness and less cost than actual equipment, the rule used at present, overlooks the fact that, for military purposes, one should seek simulators that provide *increased* performance effectiveness at *the same or lesser cost.*

Service Experience with Simulation

Information was collected on over 50 simulations, some considered by the four military services to be successful and some to have problems. Features associated with successful simulations include: high-user acceptance; timely availability of a well-developed training plan to show how the simulator should be used; genuine contribution of the simulator to training demonstrated by features for performance measurement and feedback; acceptable cost; and minimum interference by simulators with existing norms for training with actual equipment (i.e., little reduction in budgets for flying hours, vehicle miles, and steaming hours). Problems with existing simulations are attributed to inadequate or nonexistent training plans, discrepancies between the performance of simulators and actual equipment, and the absence of features considered to be important for training, e.g., motion platforms, sensors (IR, radar, EW), feedback capability. Almost all of these limitations are the result of decisions, for cost or other reasons, to procure simulations with limited or no capability for training on certain tasks. Current technology appears adequate to deal with most of the deficiencies reported, provided there is an interest in and funds are appropriated to upgrade and improve current equipment.

The following trends are observable with respect to the role of simulators for training: (1) a reduction of flying hours, up to 50 percent per year for transport aircraft, and of vehicle miles per year for armor, to pay for the cost of procuring a new distributed training system for close combat; (2) use of simulators to complement flight training for

advanced combat aircraft, with a slight reduction in flying hours; and (3) the development of low-cost, unit-training devices to be placed at most flight bases for use as modifiable, part-task trainers for electronic warfare, target recognition, and digital terrain land mass training. Current flight simulators will be phased out because they are too expensive to be placed at all flight bases. A significant trend is the development and use of advanced distributed simulators in all Services for collective, combat training but it is too soon to assess their utility for training.

Distributed Interactive Simulation

Distributed Interactive Simulation (DIS) systems now being developed have a great potential for improving unit and joint training and joint readiness (and will also have important applications in other areas, such as test and evaluation, tactics and doctrine, and mission rehearsal). However, the development of training strategies (i.e., ways to use DIS systems to improve collective training) is lagging behind development of the underlying technology in hardware and software, communications, and standards needed to support DIS. A problem that will surely arise is how best to use these systems for training (and test and evaluation) and how to evaluate their effectiveness and cost. Meaningful tests will require large numbers of people to serve as test subjects over extended periods of time, as well as development and testing of scenarios and performance-measuring techniques. Personnel must also be trained to design and conduct tests and collect reliable test data needed to evaluate the utility of DIS for training and to support a decision to procure the required equipment.

Technologies Relevant to Simulation and Training

A review of technologies critical to simulation and training included R&D on distributed interactive simulation in areas concerned with networks, semi-automated forces, terrain and environment, range instrumentation, individual combatants, virtual environments, and training technology. Areas that receive major funding ($100 million a year or more) are networks, terrain and environment, and range instrumentation. Within these areas, increased attention should be given to develop the Asynchronous Transfer Mode (ATM) protocol for DIS, support for exercise management, compatibility between data bases for terrain and environment, radio-frequency network bandwidths for range instrumentation, and communication standards. Less support is being given to methods of training, design, and use of individual combatants in DIS and SAFOR. There is a need for development of methods of evaluating performance in all areas, clarification of appropriate

applications of individual combatants (including dual-use potential) in DIS, and effective ways to use and measure the training potential of most DIS systems.

RECOMMENDATIONS

Priorities for Research and Development

Review the research and development programs on simulation and training to assure that they focus on areas of highest expenditures and potential payoff. These are aviation simulators, aviation training, OPTEMPO, joint training and readiness, and distributed interactive simulation.

Distributed Interactive Simulation

Extend efforts to evaluate the cost and effectiveness of training technology beyond the limited areas of flight and maintenance simulators and computer-based instruction. Attention should be given to methods of evaluating the cost and effectiveness of distributed interactive simulation systems such as the Close Combat Tactical Trainer (CCTT), Synthetic Theater of War (STOW), and the Multi-Service Training Testbed (MDT2), and to the use of modeling for joint training, where the major issues are likely to be validity and effectiveness.

Training Strategies

Give high priority to the development and evaluation of training strategies for the use of distributed interactive simulation for large-scale Service training and joint training for readiness. Emphasize efforts concerned with estimating performance in joint training exercises because this will provide a way to estimate joint training readiness. Development and evaluation of methods of measuring performance in joint training should be started soon in order to be in place when needed to evaluate new DIS systems, as they become available in three to five years.

Performance Data Base

Develop a data base system that provides a systematic way to compile performance data that become available from large-scale Service and joint exercises. Evaluating the effectiveness of new DIS systems for training (e.g., CATT, MDT2, and STOW) will be difficult because of the large resources needed for test subjects (military personnel for extended exercises), data collection, and personnel qualified to conduct tests and analyze

results. A comprehensive data base can provide a means to determine lessons learned from many different tests to supplement the large-scale test programs.

How Much Training is Enough

Support research and development on key issues of how much training is enough and how often refresher training must occur to maintain joint training readiness. There is a significant absence of critical information on training with respect to learning and forgetting curves and on developing optimum combinations of the use of simulators and actual equipment for various applications. This must be remedied in order to maximize the benefits available from investments in different equipment and methods of training.

Combat Models

Insufficient attention has been paid to the use and effectiveness of models used for joint and large-scale Service training. A program to evaluate the verification, validity, and accreditation of models used in unit, battle command staff, and joint training should be undertaken.

Cost-Effectiveness Paradigm

The utility of simulations has generally been decided on the basis of equal effectiveness and less cost than the use of actual equipment. Although this is an acceptable guideline, attention should be directed towards the development of simulations that increase performance effectiveness at no appreciable increase in cost or at lesser cost. Military effectiveness benefits from training for improved performance rather than merely for current levels of proficiency.

Cost Data on Training

Except for data furnished to Congress on individual training in institutions, there is a notable absence of regularly reported data on the costs of collective training in institutions and operational units, on the costs of OPTEMPO, exercises, on-the-job training, joint training and on the acquisition of training-related hardware and software. Undertake the development of cost-reporting systems that will identify, define, and make regularly available cost data on training that is needed to support policy decisions in each of these areas.

On-the-Job Training

Only limited attention has been given to the cost and effectiveness of on-the-job training, in comparison to formal training in institutions. Review current R&D activities in order to plan a more vigorous R&D effort toward on-the-job training. New developments in computer-based instruction, distance learning, and portable, miniaturized electronic job aids make this an attractive area for improving the effectiveness and reducing the costs (largely hidden) of on-the-job training.

I. PURPOSE AND BACKGROUND

PURPOSE

The purpose of this study is to examine the utility of simulation for training at the individual, unit, and Joint force levels of readiness and to provide guidelines for the development of new technology relevant to training, particularly in the area of advanced distributed simulation.

BACKGROUND

"'Simulation' has always been a difficult issue, tricky to analyze because it is surrounded by a semantic quagmire, and obscured by a miasma of emotion, over-claims, and flawed analyses, unilluminated by dependable statistics on costs or effectiveness." So writes a friend who reviewed an earlier version of this report. This report cannot eliminate the miasma, least of all that which is self-generated, but it can try to find a path through the quagmire. Let us start with the issue of readiness, the potential contribution of simulation to readiness, and the definition of some key terms.

> My highest priority for the Department is to keep our forces ready to fight.
>
> Defense Planning Guidance, Secretary of Defense,
> September 28, 1993

> The men and women who serve under the American Flag will be the best trained, best equipped, best prepared fighting force in the world, so long as I am President.
>
> President Bill Clinton,
> February 1993

> Everything is simulation except combat.
>
> Defense Science Board, 1993

Winning the cold war in a bi-polar world did not, it turns out, lead to general peace in our multi-polar world. Reductions in the defense budget and in force structure, together with changes in the external threat, increase the difficulty of sustaining military readiness to deal with less predictable adversaries in less obvious places. The components of readiness

include training, materiel, personnel, supply, and infrastructure. Although the focus of this paper is on simulation's role in training for Joint readiness, we believe that advanced distributed simulation has utility not only for training, but for the other components of readiness as well. The reason is that military exercises conducted in synthetic theaters of war provide an opportunity not only for training but also for evaluating concepts and procedures for weapon systems, supply, tactics, and doctrine—whether these be "conventional" or innovative. An indirect but potentially very powerful contribution that simulation can bring to defense planning and management is that the Department's disparate communities, such as those concerned with research and development, operations, acquisition and the budget, may begin to identify and use common methods, assumptions and findings in developing policy, strategy, budgets, and tactics.

We are more dependent on simulation than is generally acknowledged. New weapons, such as aircraft, tanks, and ships, are now designed and developed with a major reliance on simulation; this reduces the need for mock-ups, eliminates some tests of hardware, and shortens redesign of components to assure interoperability on the battlefield. Of course, confirmational system testing remains necessary, but now it can occur towards the end of the development cycle. Decisions to build the major components, often at great cost, can be made with far less risk. Battle plans and, to some extent, actual tactics can be based more reliably on extensive simulation with combat models. The Defense Science Board (DSB) (1993) in its recent report on simulation, readiness, and prototyping, said that "Everything is simulation except combat." The DSB examined the potential use of simulation for many purposes of concern to defense, such as training, test and evaluation, mission rehearsal, and system acquisition. It is clear that simulation will have much widespread utility, but consideration of applications outside training is beyond the scope of this effort.

It is unthinkable that training to cope with potentially catastrophic events, such as the failure of a nuclear reactor, or of an engine on an Apollo lift-off, or of the first attempt to land on the Moon, could be conducted in any way other than by the use of simulators. Some widely accepted examples of successful training that depended on simulations are shown in Figure I-1.

Landing on the Moon	Actual training not possible on Earth
Top Gun Fighter Weapons School	Improved Navy exchange ratio in air combat over North Vietnam from 2.4 to 12.5
Commercial Airlines	FAA: Simulator training alone qualifies a pilot to fly a new airplane for the first time on a revenue flight
National Training Center	OPFOR experience at NTC (simulation) is a decided advantage
Nuclear power plants	No significant accidents (after Three Mile Island) in military and civilian operations
Canadian Armor Trophy	Extensive training with SIMNET and UCOFT helped Army win CAT for the first time in 1987
73 Easting	Participants report that success in Gulf War battle was based on tactical experience gained in SIMNET, NTC and Grafenwoehr

1-4

Figure I-1. Examples of Successful Training with Simulation

It should be noted, however, that such reliance on simulation is an artifact of our generation. When, in World War I and again in World War II, the armed forces of the United States were called upon to redress abject military unpreparedness, they were required to simulate, to conduct training with wooden mockups of weapons, lacking as they did the real ordnance. Ever since, for military professionals, "simulation" has been a loaded word, a term applied invidiously to any training involving a simulacrum of military equipment, or admitting pretended movement, shooting, or communications. Even today, in virtually any military headquarters, stentorian proclamations can be heard to the effect that "this command does not simulate! It trains by actually doing everything it must do in combat, with real people, real equipment, and real weapons!"

Military reservations about simulation revolve around the contemporary issue of OPTEMPO (operating tempo reported as flying hours per month, vehicle miles, or sailing days per year). OPTEMPO occasions much of the cost of maintaining military forces in a time of nominal peace. Despite its high cost, it offers a major opportunity to prepare for war by training and practice with real weapons and vehicles. No pilot, sailor, or tanker

joined the Service to become proficient in combat skills by "sitting in a box" and practicing with a simulation.

The budgeting conventions of the Department of Defense and the Congress have almost always purchased simulators by reducing OPTEMPO, seeking both to reduce overall expenditures and to offset the cost of procurement. The word "simulation" then bears the burden of two generations of short-sighted Service programming, during which the Office of the Secretary of Defense (OSD) and the Congress were taught that a simulator, especially an expensive aviation simulator, should be funded only when test data could be produced to demonstrate that the device would "pay for itself" by being demonstrably cheaper than actual equipment for training and at least as effective.

Recent advances in simulation technology patently require that the Department of Defense and the armed Services lay aside the baggage surrounding the terminology, and look anew at opportunities presented. A useful way to begin would be with definitions; these are presented below.

The present leaders of the Department of Defense perceive "simulation" as a major policy instrument, recourse to which can enable the Services to thrust ahead buoyed by the strong, commercially driven technologies of the Information Age.[1] The Secretary of Defense recently remarked that "taking units to the field, aircraft to the air, or ships to sea is no longer the only way we can do effective training. Simulation is another. And the combination of field tests and simulation is probably the most effective way to train, and we're just beginning to introduce simulation."[2]

During the past twenty years, the U.S. military services have employed three forms of simulation to portray, for training or any other purpose, what happens when one military force engages another: (1) constructive simulations, mathematical models of combat, from duels between weapons to wars among nations; (2) live (real or subsistent) simulations, involving engagements among actual military forces and vehicles with simulated weapon effects, and (3) virtual (apparently real) simulations, comprising interactions among manned simulators of weapon platforms, operating in wholly synthetic, computer-

1 William J. Perry, Secretary of Defense, Remarks to the Global Air and Space 1994 International Forum, 5 May 1994.

2 Ibid.

generated environments.[3] While constructive and live simulations have been improved slowly over the past century or more, virtual simulation is a recently actualized, dramatic, new capability based on modern computers and displays. Further, only in the past decade has inter-computer programming and communications made it possible to obtain coherent outcomes from simulation using all three forms of simulation interactively. Hence, the current thrust in development of advanced simulation is to enable a "synthetic theater of war" (STOW) using distributed interactive simulation (DIS) for Joint (inter-Service) and combined (inter-allied) training.

Military training occurs in one of four distinctive environments, depending upon whether it is training for individuals or collectives, and upon whether it takes place in an institutionally structured environment, or within the resources of a military unit.[4] Thus, in considering how, where, and when to introduce simulation for training, the following paradigm is helpful:

	Where training occurs	
Who is trained	Institution	Unit
Individual	1	2
Collective	3	4

The Services have found it easiest to introduce simulation for training and to demonstrate its cost-effectiveness in Block 1, individual training in an institution. This is so because (1) simulation is most efficiently used within a time-constrained curriculum by an institutional staff that can assure continuous usage of expensive simulators, computer-

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3 P. F. Gorman, "The Future of Tactical Engagement Simulation," Proceedings of the 1991 Summer Computer Simulation Conference, The Society for Computer Simulation (SCS), Place, D., ed., pp. 1181-1186.

4 For a further discussion, see P. F. Gorman, "Training Technology," in Trevor Dupuy, editor-in-chief, *International Military and Defense Encyclopedia*, Macmillan Publishing Company, Riverside, NJ, 1993.

based battle games or other simulative equipment, and (2) because reliable data on training transfer is easier to collect from relatively homogenous populations of students while they are captives in scheduled courses.

Conversely, Services procure expensive simulations for Block 2, individual training in an operational unit, at the hazard of subsequent adverse audits by the Government Accounting Office showing that no consistent, effective employment of the simulation apparatus had occurred amid the hurly-burly of a unit's routine activities. Because units often can neither assure adequate utilization nor reliable records, simulations are typically maintained by a training center or other institution located nearby, so that usage can be efficiently scheduled, and spread across personnel assigned to several units. Examples are aviation flight simulators, and shoulder-fired air defense weapon simulators. As the price of computers and displays drops, risks associated with introducing simulation for training in units will decline. For example, the Air Force is developing Unit Training Devices that will be located at every flight base; these are relatively inexpensive devices that can be used for training pilots on a variety of tasks (see Chapter IV).

Block 3, collective training in an institution, is an area that has undergone major growth over the past two decades, and usually depends upon either institutionally directed wargaming, a constructive simulation (such as the Army's Battle Command Training Program) or upon an instrumented range, a subsistent simulation using a network of weapon emulators and positioning sensors that enable a synthetic combat environment. Examples of the latter are "Strike University" (Fallon Naval Air Station, Nevada), RED FLAG (Nellis Air Force Base, Nevada), and the Army's Combat Training Centers (Fort Irwin, California; Fort Polk, Louisiana; and Hohenfels, Germany). The Services also maintain less ambitious instrumented ranges for smaller tactical performances, such as the Navy's Air Combat Maneuvering Instrumentation. Introducing advanced technology enabling joint and combined exercises on such ranges, exploiting all three forms of simulation, constitutes a major opportunity to enhance and estimate readiness.

Block 4, collective training in an operational unit, is clearly another high-payoff area for readiness but, to date, relatively little investment has been made in simulation designed expressly for use in units, by unit commanders, training their forces for combat readiness. The Services have to date resisted building training subsystems into their battle

equipment. Even exceptions, notably MILES[5]-type laser-weapon-emulators or ACMI[6] pods, involve strap-on devices. Up until the recent past, investments in simulation for collective training at institutions (Block 3) could be more readily amortized over time than buying simulation equipment to be used by units. But as digitization of the battlefield proceeds, as dependence on digitally transmitted information grows throughout the armed forces, opportunities increase to build into unit equipment itself the means to generate a synthetic battle environment for training or for operational rehearsal. Hence, collective training in units (Block 4) ought to be perceived as a promising growth area for simulation for training.

We can now see a convergence of two streams of events. Reductions in the funds available for OPTEMPO (i.e., combat training in the field) reductions in the number and size of ranges available for such training, coupled with concern for noise and environmental factors, all combine to reduce the opportunities for live simulation and combat training with actual equipment under realistic conditions. However, large advances in computer capability and in high-capacity global communications—much of it the result of commercial interest—have facilitated the growth of constructive and virtual simulation. The current development of distributed interactive simulation (DIS), or geographically broadcast virtual simulation, motivates the concern of this paper with the military value of simulation for training.

DEFINITIONS

For sake of clarity, we define and discuss briefly some of the terms and concepts used throughout this report.

Individual and Collective Training

Military training falls into two classes called Individual and Collective Training. Individual training provides the skills needed to accomplish particular jobs, associated with about 500 Military Occupational Specialties. These skills are developed by almost 20,000 courses in recruit, officer acquisition, specialized skill, and flight training and by professional development education for officer and enlisted personnel. Collective training refers to development of the skills needed, in addition to the individual ones, for

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5 Multiple Integrated Laser Engagement System

6 Air Combat Maneuvering Instrumentation

individuals to operate as crews or teams in aircraft cockpits, command and control stations, ship's bridges, communication centers, tanks, and so on.

Institutional and Unit Training

Formal individual training occurs at schools (i.e., fixed facilities with faculty and administrative support); this is called Institutional Training. Most collective and some important individual training—on-the-job or experiential learning—occurs in operational units and commands. This is called Unit Training. Although most units will have a training section, both the trainers and trainees must accommodate to the varying demands placed on operational units. Unit training schedules and curricula are subject to constant change; this rarely occurs, except by design, in institutional training. As noted above, some of the most effective institutional training for collectives is subsistent simulation for units exercising under a faculty at an instrumented range.

The student loads and costs of individual training at institutions are reasonably well known because they are reported annually to Congress in the Military Manpower Training Report. This cannot be said of any other type of training, either in schools or in military units. Each Service is responsible for unit training, and for providing combat-ready components to the U.S. combatant commands, i.e., the CINCs, such as the Commander(s) in Chief, U.S. Atlantic Command (USACOM), U.S. Pacific Command (USPACOM), and Europe (USAEUR). Because of the draw-down in force structure, joint training to develop and assess joint readiness (i.e., preparation for the ways in which forces of the several Services will operate together) will now receive special attention by the Services, Joint Staff, and the Office of the Secretary of Defense.[7] A major significance of distributed interactive simulation is the contribution it may make to opportunities for Joint exercises, and for assessing readiness not otherwise available or too costly, as well as for the compilation of performance data on how well joint forces can accomplish various types of missions or exercise scenarios.

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7 Task Force on Readiness, Defense Science Board and Secretary of Defense; Senior Readiness Oversight Council, Deputy Secretary of Defense; Readiness Working Group, Under Secretary of Defense (Personnel and Readiness); and Joint Requirements Oversight Council, The Joint Staff.

Simulation

The imitative representation of one system or process by means of the functioning of another.

Webster's Ninth New Collegiate Dictionary,
Merriam-Webster Inc., Smithfield, MA, 1987

An inferior substitute imitating an original.

Roget's II, The New Thesaurus,
Houghton Mifflin Company, Boston, MA,1980

In principle, a simulation, which is the product of a simulator, is a representation of a system (including organizations) by another system, the "other system" being the simulation. The first system need not be real; it too may be a simulation (and so forth) although such iteration is rarely required.

James T. Westwood in Trevor N. Depuy, editor-in-chief,
International Military and Defense Encyclopedia,
MacMillan Publishing Company, Riverside, NJ, 1993

The term *simulation* refers to the general process by which certain real-world systems, operations or phenomena are initiated using representational devices such as models, game boards, computers or other equipment. The focus of the term is on the process of imitating (or simulating) the reality of concern, rather than on the models or items used or the rules to be followed.

Frances B. Kapper in Trevor N. Depuy, editor-in-chief,
International Military and Defense Encyclopedia,
Macmillan Publishing Company, Riverside, NJ, 1993

Simulator

A device that enables the operator to reproduce or represent under test conditions phenomena likely to occur in actual performance.

Webster's Ninth New Collegiate Dictionary,
Merriam-Webster Inc., Smithfield, MA, 1987

A simulator is a device or facility that produces simulations.

James T. Westwood in Trevor N. Dupuy, editor-in-chief,
International Military and Defense Encyclopedia,
Macmillan Publishing Co., Riverside New Jersey, 1993

Stand-Alone Simulators

Flight simulators to train pilots were built almost as soon as aircraft were designed. Other types of simulators are used to train operators and maintenance personnel for such

purposes as crew cockpit coordination, in-flight refueling, identifying malfunctions in radar and sonar systems, and controlling the diving of submarines. All of these simulators are grouped here on the basis that they are self-contained and stand-alone devices that are used to train personnel in many of the individual and crew skills required to operate and maintain weapon and support systems. The Services use thousands of these devices. In the future, some of these devices may be modified so that they can interact with other simulators in distributed interactive simulation systems.

Networked Interactive Simulators

The environment that is produced by networks of interactive simulators used for combat training is called "virtual simulation" and SIMNET (Simulator Networking) is the best known prototype of this class of large scale simulation. Networked simulators are designed to be used for unit and joint training in large scale, two-sided engagements with various types of weapon systems and command and control groups. Individuals must have been trained to operate weapons, e.g., tanks and aircraft, before they can receive collective training using networked simulators. Future improvements in the physical and functional fidelity of networked simulators, as well as reductions in their cost, may permit both individual and unit training to take place, using the same simulator. Networked, interactive simulations now under development include:

BFTT	Battle Force Tactical Trainer
BFIT	Battle Force In-port Training
CCTT	Close Combat Tactical Trainer
AGPT	Ausbildungsegerat Gefechtssimulator Panzer Truppe (German SIMNET)
CATT	Combined Arms Tactical Trainer (British SIMNET)
MDT2	Multi-Service Distributed Training Testbed
STOW	Synthetic Theater of War

Instrumented Ranges

Instrumented ranges can record the location and timing of events that take place between opposing sides in simulated combat of troops using actual weapons and platforms, called "subsistent simulation" or "live simulation." These ranges provide objective performance data on both sides for use in after-action reviews for unit, joint, and combined Service training.

Computer-Based Combat Models

Models may be either iconic (enlarged or miniature versions of real objects), symbolic (abstract versions, words, diagrams), mathematical, or computer-based. The use of computer-based combat models in simulation is called "constructive simulation" (Defense Science Board, 1993).

The catalogue (12th edition) of The Joint Staff lists about 1000 computer-based models that simulate all types of combat and combat support, and that are employed for many purposes, analytical as well as training, in the Department of Defense. Examples of combat models are Corps Battle Simulation (CBS, Army), Janus (Army), Enhanced Naval Wargaming System (ENWGS, Navy), Research, Evaluation, and Systems Analysis (RESA, Navy), Air Warfare Simulation (AWSIM, Air Force), and Joint Conflict Model (JCM, Joint Staff). The widespread use of combat models for many types of military analyses is a measure of their usefulness, convenience, and popularity. However, their validity has been strongly challenged (see Davis and Blumenthal, 1991).

Distributed Interactive Simulation

The concept of Distributed Interactive Simulation (DIS), also called Advanced Distributed Simulation, envisions that any combination of stand-alone simulators, networks of simulators, live exercises on instrumented ranges and computer-based combat models may be employed interactively and in real time. A good example is the Synthetic Theater of War (STOW), now being developed by the Advanced Research Projects Agency (ARPA) with multi-Service participation for joint combat exercises. This type of simulation will support exercises that permit interactions in real time between actual vehicles and weapons on instrumented ranges (e.g., aircraft at Red Flag and Top Gun, ground vehicles at the National Training Center, and naval vessels off San Diego), networked simulators, and computer-based combat models.

Virtual Reality

This term is given to a class of simulators that produce a so-called experience of "total immersion" for the participants. The devices that are used to produce such striking effects include helmet-mounted displays (to produce three-dimensional visual imagery and auditory effects), instrumented gloves, force feed-back to various parts of the body, control devices (in addition to gloves), motion bases, and the computers, data bases, and algorithms needed to create a semblance of generally simplified reality. The effects,

although still cartoon-ish in nature, can be impressive. Systems of this sort have great possibilities for remote manipulation and micro-surgery (even at a distance, with visual and force feed-back) in the real world, as well as for training and amusement.

Virtual reality is a technology that is now undergoing rapid development for such varied purposes as entertainment, medical education and surgery, architectural design and tactical planning. Virtual reality is not considered in this paper except for some technology to support interfacing with virtual environments.

On-the-Job Training

On-the-job training (OJT) is "Any pre-planned use of work resources (people, equipment, facilities) in the work environment primarily for the purpose of training someone to produce work." (Carpenter-Huffman, 1980, p. 2). On-the-job training occurs in operational units after the completion of technical training courses in schools. Although all training in units might be called on-the-job training, in practice OJT refers only to the real world training of individual specialty skills still needed after the completion of school. For some types of skills, training may occur either at schools (followed by OJT) or only by on-the-job training (see Chapter II).

Cost and Effectiveness

Training is intended to develop a specified level of proficiency in a designated subject matter area, such as communications, radar maintenance, aircraft navigation, sonar operations, or data processing. Effectiveness refers to a measure of the extent to which one method of training (e.g., classroom instruction, computer-based instruction, simulation, field exercises) succeeds in helping trainees acquire the skills and knowledge specified by the standard established for completion of a course. Cost refers to the expenses incurred in providing training and may include some or all of the costs of course development, including research, test and evaluation of training procedures and equipment, acquisition of the hardware and software needed for training, and operation and maintenance (i.e., the delivery of training). In this paper, we take the position that information on both the effectiveness and cost of a method of training, compared to some alternative method, is needed in order to determine the preferred method of training.

ADVANTAGES AND DISADVANTAGES OF SIMULATORS AND SIMULATIONS

We conclude the introduction to this report and a description of its background by listing many of the advantages and disadvantages often found in the literature on simulation. They represent conventional wisdom and may or may not be correct when applied to particular simulators and simulations used for specific purposes. The remainder of this report attempts to supplement such wisdom by providing and discussing data and information that can be used to support developments in technology and policy intended to improve the utility of simulation for training and joint readiness, wherever it may be needed.

Advantages

- Trains many tasks as well as would the use of actual equipment.
- Costs less than actual equipment to procure and use.
- Provides training that otherwise requires use of actual equipment.
- Permits training for dangerous and potentially catastrophic conditions not otherwise possible in actual equipment.
- Reduces risk, safety hazards, and wear-and-tear from use and maintenance of actual equipment, and extends useful life of equipment needed for combat.
- Reduces impact that actual equipment has on environment, and the noise and use of ranges have on communities.
- Protects operational security of tactics and mission rehearsal, of electronic warfare, and sensitive performance characteristics of new weapons.
- Provides features needed for instruction and feedback, including performance measures.
- Saves on use of fuel, munitions, support facilities.
- Provides initial familiarization, trains procedures (less so for advanced students), and avoids risk to actual equipment by novices.
- Permits training not readily affordable with actual equipment.
- Permits use of actual or anticipated threat conditions to examine doctrine, effect of the combat environment, and potential responses.
- Permits testing of effectiveness of plans and tactics prior to actual operations.
- Permits joint training of DoD forces and of coalition forces.
- Can recreate significant battles to identify key events and to train leaders.

Disadvantages

- Could adversely affect training readiness if use of simulators reduces OPTEMPO, as well as confidence in use of actual equipment.
- Uninformed by data from actual performances of weapon systems and service crews, virtual and constructive simulations can be dubiously valid.
- Require funds to procure and use.
- May instill habits that are incorrect for use in actual equipment.
- Limited fidelity of visual resolution, sensors, aerodynamics, and motion platforms can lead to inadequate or misleading training.
- Differing response characteristics of visual displays and of motion platforms often leads to motion sickness.
- There is a potential compromise of security if sensitive tactics and equipment features are gained by access to networks that support interactive simulators.
- Accurate performance of weapons and platforms in simulations requires accurate engineering models and data that may not be available or are expensive to develop in such areas as aerodynamics and hydrodynamics, lethality of weapons, vulnerability, weather, visibility, target detection with various sensors, terrain.

Unresolved Issues in Simulation

- Identification of types of training that cannot be accomplished using distributed interactive simulation and development of viable alternatives.
- Validation, verification, and accreditation of high-level models to be used in estimating Joint readiness and training status.
- Organizational, cultural, and management issues that must be considered if distributed interactive simulation is implemented on a grand scale.
- Optimum combinations for use of simulation and actual weapons and platforms in exercises to achieve maximum performance effectiveness at least cost for most applications.

II. BUDGETS RELATED TO SIMULATION AND TRAINING

In this chapter, we try to identify the costs of various components of simulation and training, such as the procurement of simulators and simulations, training at schools and in the operational commands, and research on methods of training. To the extent possible, we try to identify trends in the budgets for these activities over recent years. We also present this data in a common format that provides estimates of annual expenditures in these areas.

Except for individual training at institutions, there is no single source that identifies all of the funds that are allocated to simulation and training each year. This is due largely to the fact that funds that support individual training at institutions come from different appropriations than those for other types and places of training; in addition, funds for unit training come from appropriations that also support operation and maintenance, base support, and OPTEMPO. An attempt to estimate the costs of training from diverse accounts is likely to be incomplete and probably lack standard definitions as to what the various cost elements relevant to training should or should not include. The actual costs of on-the-job training in units are virtually hidden and are very difficult to identify. To the best of our ability, we will point out whatever qualifications may apply to the cost data we present. Nevertheless, we believe that, despite its imprecision, the information presented here is the most comprehensive compilation of costs associated with simulation and training that is now available.

The costs of individual training at institutions are known because they are reported annually to Congress in the Military Manpower Training Report (MMTR). The MMTR describes the costs and amounts of individual training at institutions for recruit, skill, initial officer, and flight training and professional development education. This report does not, for example, provide information on the costs or amounts of on-the-job technical training that takes place in the operational commands to which personnel are assigned after completing initial individual training; these costs, if they were knowable, are funded by the Operation and Maintenance (O&M) and other accounts. Collective training occurs mainly, but not exclusively, in operational units and is supported by funds in the O&M accounts that also provide for base operations, supplies and maintenance. There is no assurance,

except as may be determined by a subsequent audit of actual expenditures, that funds allocated to collective training were actually spent for that purpose; such audits are not conducted regularly. Local commanders have, and should have, discretionary authority to re-distribute these funds as dictated by local circumstances. It is not unheard of, therefore, that funds intended for training are actually spent to repair broken water mains or to provide supplies for which no other funds are available. Funds for the procurement of simulators are sometimes (but not uniformly) included in the costs of the weapon and support systems for which they provide training. Funds for the development and procurement of wargames and combat models by the Unified and Specified Commands are reported here only because they became available as the result of a special inquiry by the Inspector General. Other comments on our cost data are made below. Sources of the data that are reported here are identified in the figures and text that follow.

Procurement

Figure II-1 shows total projected DoD outlays for simulation-related activities by the Services for the seven years FY 1991-97, in constant FY 1992 dollars. This information is derived from Department of Defense data files on prime contract awards for Training Aids and Devices, according to Federal Stock Classification 6900, and on program summaries of planned procurements made available by the Services; it is collected by a commercial organization that prepares market surveys and is, therefore, not an authoritative document. The total amount over this period is $13.5 billion for an average of about $1.9 billion per year. These funds provide for the purchase and maintenance of simulators, as well as for research, development, and test and evaluation of simulators and training devices. The amounts spent by each Service are similar but fluctuate from year to year as a result of a large procurement related to the introduction of a major weapon system by a particular service. Marine Corps outlays are included in the Navy figure; "Other" is primarily the Defense Logistics Agency.

The same data, in Figure II-2, show that the procurement of simulators and services needed for their support account for over 80 percent of the total outlays related to simulations; RDT&E accounts for about 18 percent.

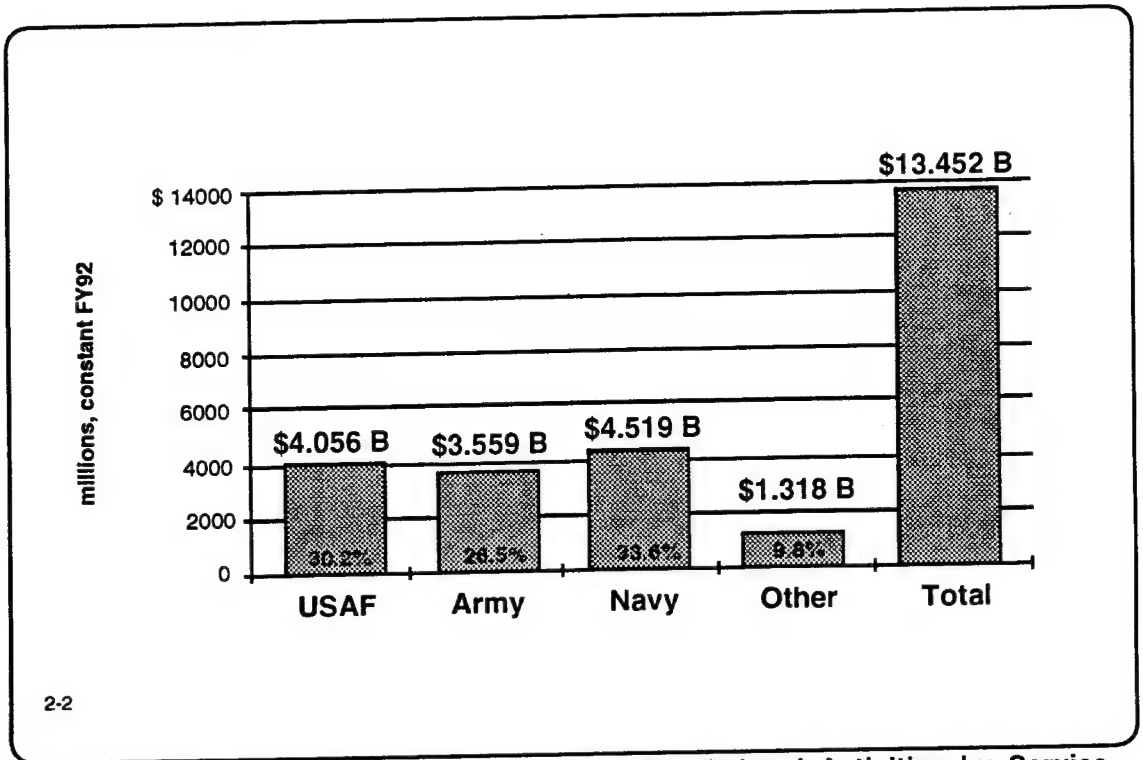

Figure II-1. Total DoD Outlays for Simulation-Related Activities by Service, FY 91–97 (Source: Frost & Sullivan, 1993, p. 1–8.)

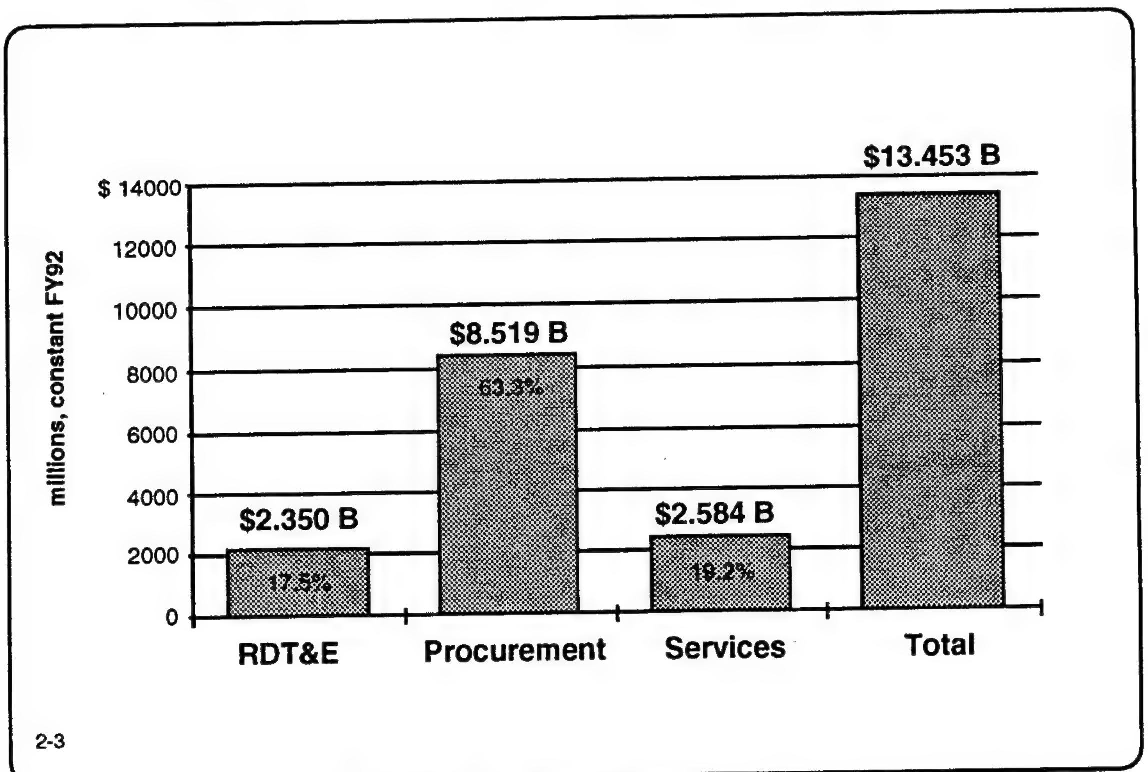

Figure II-2. Total DoD Outlays for Simulation-Related Activities by Functional Area, FY 91–97 (Source: Frost & Sullivan, 1993, p. 1–5)

Figure II-3 shows DoD outlays for the procurement of simulators by type of weapon and support system. A brief description of the categories follows:

Aviation	Includes specialized aircraft-related training devices, in addition to conventional flight simulators. It also includes training devices embedded in or carried on aircraft for in-flight training of pilots and non-pilots (navigators, engineers). It does not include procurement of training aircraft or of pilot training services that utilize only aircraft.
Non-System Training Devices	Includes training devices of various generalized types not identified specifically with a particular system, e.g., devices for electronics and hydraulics training and computer-based instruction devices. (May include training devices for small systems.)
Missiles	All types of training devices associated with missiles.
Electronic Warfare	Intelligence collection and countermeasures training devices not specified as onboard ships, aircraft, submarines, or armored vehicles.
Maintenance	System-specific devices for training military personnel to repair aircraft, ships, and other platforms and the equipment associated with them.
Battlefield Armor Command	All battlefield or soldier-related training equipment. Training devices for tanks, fighting vehicles, and other armored weapons systems. Training devices for command, control, and communications systems (C3); tactical and strategic wargames; and other leadership training.
Surface ships	All training devices and equipment associated with ships and surface warfare.
Submarines	All training devices and equipment associated with submarines, submarine warfare, sonar and antisubmarine warfare.

The procurement of simulators for aviation systems accounts for about \$5.6 billion, or 72 percent of funds spent for simulators for all types of weapon systems (\$7.8 billion for FY 1991–1997). This is followed by \$1.7 billion (23 percent) for Non-System Training Devices. The procurement of simulators for all other weapon systems accounts for \$0.4 billion (5 percent).

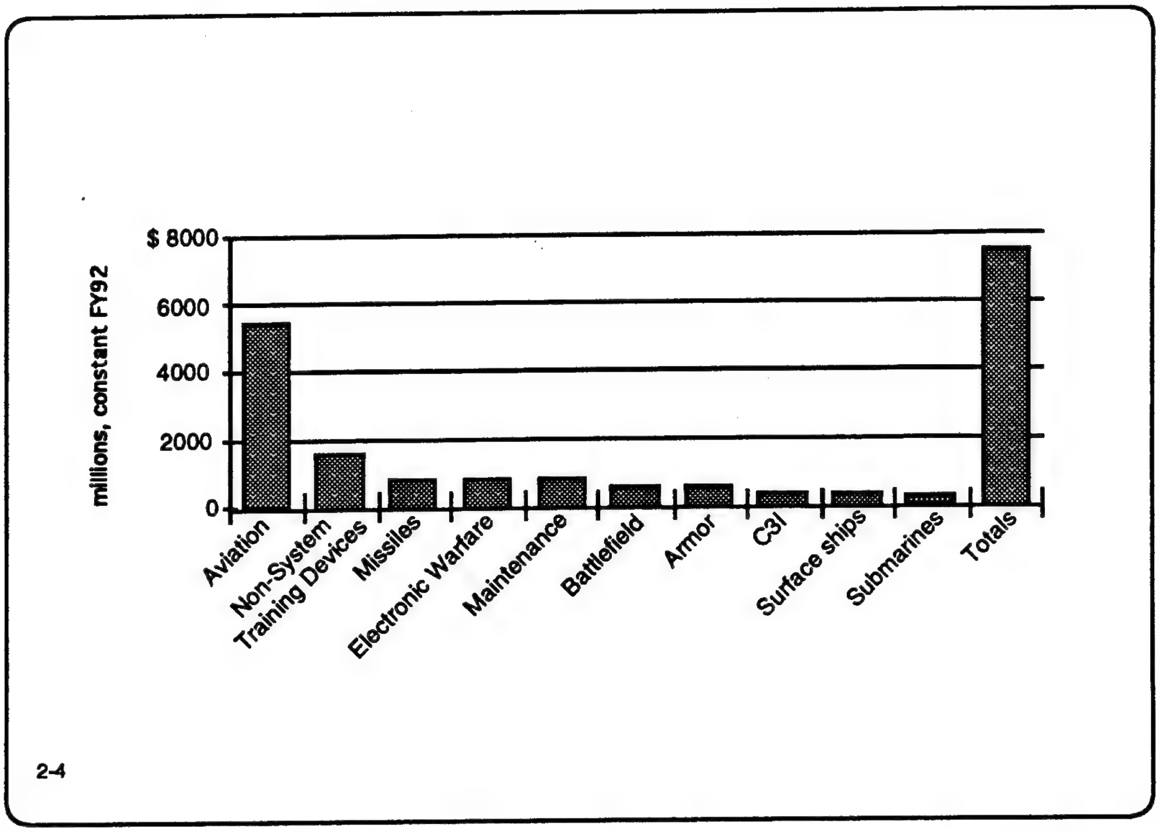

Figure II-3. Total DoD Procurement for Simulation by Weapon and Support Systems, FY 91–97 (Source: Frost & Sullivan, 1993, p. 1–8)

Modeling and Simulation

Annual expenditures for modeling and simulation in support of training in the Unified and Specified Commands for 1991 and 1992 are shown in Figures II-4 and II-5. Estimates of the costs of modeling and simulation in the Unified, Specified, and the Combined Forces Commands were collected from the fund managers at the Defense Modeling and Simulation Office and the Joint Staff, J-7 and J-8, by the Inspector General of the Department of Defense (Inspector General, 1993).

> Distinguishing between funds explicitly earmarked for training models and those earmarked for other models comes down to some very subjective choices. Despite the subjectivity of the data, however, the two graphs effectively compare general funding patterns across the commands. As the different scales between the two graphs imply, the CINCs received greater funding support in 1991 (about $25 million) than they did in 1992 (about $12.5 million) from the three funds. (Inspector General, 1993, p. 24)

Similar data on modeling in the individual services are not available.

Figure II-4. Annual Expenditures for Modeling and Simulation in Support of Training in the Unified and Specified Commands, 1991 (Source: Inspector General, 1993)

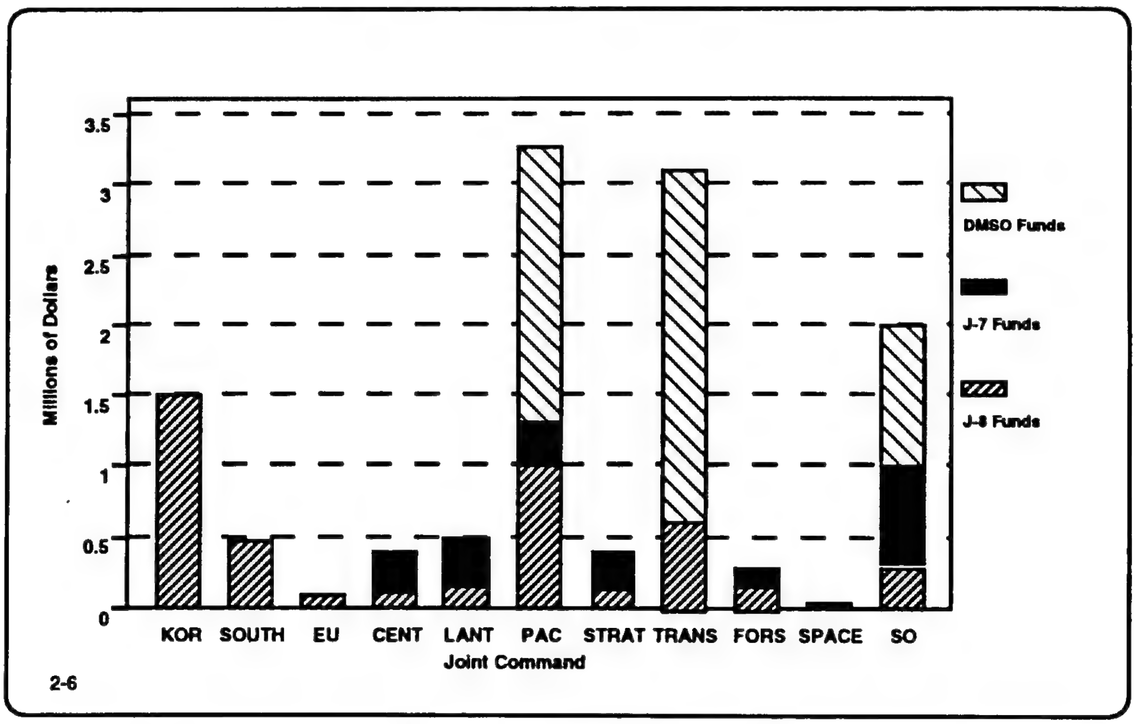

Figure II-5. Annual Expenditures for Modeling and Simulation in Support of Training in the Unified and Specified Commands, 1992 (Source: Inspector General, 1993)

> The [amount of] funds available through the Joint Staff have been fairly consistent: about $8 to $10 million through the Joint Modeling and Simulation Support Program and about $25 million through the CINC Initiatives Fund. The first two years of Defense Modeling and Simulation Initiative funds have hovered around $30 to $40 million.
>
> Inspector General, 1993, p. 24.

> Unlike the Defense Modeling and Simulation Initiative funds, not all of the Joint Staff monies for the two funds discussed are spent directly on modeling and simulation support for training. The principal purpose of the J-8 funds is to develop and maintain analytical capability within the Unified and Specified Commands. The primary purpose of the J-7 funds is to support unanticipated, emergent needs of the Unified and Specified commands. For example, a review of the 1992 expenditures under the CINC Initiatives fund, reveals about $2 million, or about 10 percent, spent directly on modeling and simulation support for the CINCs. During the same period, the Joint Modeling and Simulation Support Program spent about $5 million, or 50 to 65 percent on software and hardware to support modeling and simulation.
>
> Inspector General, 1993, p. 24

Individual Training

Funds allocated to the training of individuals and the amount of individual training provided in man-years at schools are shown in Figure II-6. The training load, in man-years, combines the time spent by all students in all courses, whether they last days, or years. In FY 1994, about 174 thousand man-years of training were provided at a cost of about $14.4 billion; this is a reduction of 7.4 thousand (4 percent) in man-years and $1.2 billion (8 percent) in funds from FY 1993.[1] When looked at as the number of people who are trained, this accounts for about 1.2 million graduates of over 20,000 courses in FY 1994. In terms of funding, the Army spends about 20 percent more than the Navy for individual training in FY 1994 and almost 70 percent more than the Air Force. It is intriguing to note that the ratio of support to individual training is about 0.8 for man-years and 0.3 for funds (FY 94).

Figure II-7 shows the training loads (man-years of training) and funding for each category of individual training, such as recruit training, skill training, and flight training. The largest amount of funds for FY 1994 is allocated to Specialized Skill Training

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1 For FY 1995, the requested training load is 180,000 man-years (an increase of 3.5 percent over FY 1994) and funding of $14.0 billion (a decrease of 2.9 percent from FY 1994). (MMTR, 1995)

	Man-Years FY 1993	FY 1994	Funding (millions) FY 1993	FY 1994
Active Components				
Army	54,667	52,628	$6,151	$5,406
Navy	48,900	44,207	4,824	4,515
Marine Corps	18,831	19,653	1,381	1,302
Air Force	26,112	26,802	3,307	3,192
Subtotal	148,510	143,290	$ 15,663[a]	$ 14,415[a]
Reserve Components				
Subtotal	32,883	30,690	($ 1072)	($ 1009)
Total	181,393	173,980		
Support of Individual Training[b]	152,000	138,000	($ 4032)	($ 4246)

[a] Includes funds for Reserves and Support
[b] Military and civilian

2-7

Figure II-6. Individual Training Loads and Funding by Service, FY 93 and FY 94 (Source: Military Manpower Training Report, FY 1994, 1993)

	Man-Years FY 1993	FY 1994	Funding (millions) FY 1993	FY 1994
Recruit Training	36,468	32,139	$1,516	$1,161
Officer Acquisition Training	18,669	17,594	530	511
Specialized Skill Training	100,817	97,760	4,866	4,138
Flight Training	3,830	4,037	2,332	2,175
Professional Development Education	12,551	13,322	964	906
One-Station Unit Training (Army)	9,058	9,128	352	269
Direct Training Support			768	738
Training Base Support			3,102	3,365
Training Management Headquarters			162	143
Reserve Component Pay and Allowance			$1,072	$1,009
Total	181,393	173,980	$15,664	$14,415

2-8

Figure II-7. Individual Training Loads and Funding by Type of Training, FY 93 and FY 94 [Source: Military Manpower Training Report, FY 1994, 1993]

($4.1 billion), followed by Flight Training ($2.2 billion). When we divide these funds by the number of man-years of training each provides, we find that Specialized Skill Training costs about $42 thousand per man-year while Flight Training costs about $539 thousand per man-year. Further, initial flight training lasts about one year while specialized skill training lasts one-half year or less. Clearly, flight training is by far the highest cost per person type of individual training in the Department of Defense. Note that the funds shown for the various types of training ($9.2 billion) do not include a proportional allocation of overhead funds ($4.2 billion for direct training support, training base support, headquarters); or of Reserve pay and allowances ($1.0 billion). If these were included, the costs of the various types of training would be 57 percent larger than those shown in the table, although the total would not change.

Unit Training

Much less is known about the cost of individual and collective training in units and of OPTEMPO than about individual training at schools. When individual training at school is completed, additional individual (on-the-job) and collective training is accomplished in the operational units to which individuals are assigned. Operational training develops the collective skills needed to perform well in combat; this includes crew and unit training at all levels within the Services and in combined and Joint exercises. Unit training is supported by funds in the Operation and Maintenance accounts that also provide for base operations, security, and maintenance of base facilities. There are no regular reports on the amount of funds allocated to on-the-job training, unit training, and OPTEMPO; there are a few ad hoc estimates of these costs.

In work on unit training performed for the Office of the Assistant Deputy of Defense (Personnel and Readiness), the Logistics Management Institute (LMI) examined all Program Elements (PE) in the Operation and Maintenance (O&M) funds in the President's budget submission to Congress for FY 1993. The total O&M budget for FY 93 was $67.2 billion. Estimates were made of how much each PE contributes to unit collective training, in accord with these definitions:

> Operational Units - These are the units that are being trained. They are ships, aircraft squadrons, divisions, special warfare groups, etc.
>
> All O&M is Training - These are special organizations with the primary mission of providing unit collective training that are not included in Major Force Program 8.

Much Support - These are organizations that we feel are essential to unit collective training, but which may have significant other missions. This includes such things as operational headquarters and tactical support units in this category.

Some Support - These units are deemed to provide some, but less support to unit collective training. These include such units as management headquarters.

No Support - These are PEs that are not believed to contribute to unit collective training. This should be not construed to be an indicator of their importance or contribution to combat forces operations. We have included such things as PEs specifically related to the acquisition and support of new equipment in this category.

Unknown - These are PEs with classified or missing PE descriptions.

Logistics Management Institute, 1993, p. 1

We estimated the portion of each operational unit PE's O&M that is related to unit collective training.

In the case of Army PEs, we were able to identify the O&M funding that Army considers unit collective training for every PE through the training MDEPs [Management Decision Packages]. We used the percentage of total O&M allocated to the operational unit PEs to estimate Army operational unit collective training costs. We used the ratio for Army operational units for our estimation of Marine Corps ground units.

We compared OPTEMPO (Flying hours) funding from Navy OP-20 and DoNSched reports to total O&M to establish a ratio for estimating unit collective training for Navy, Marine and Air Force aviation operational units.

Ships unit collective training costs were estimated by comparing OP-41 steaming hours costs to total O&M in ships PEs.

We estimated that 30% of "Much Support" O&M and 10% of "Some Support" O&M are costs of unit collective training. We believe that this provides a reasonable starting point for evaluation unit training costs from the FYDP. PEs do not, however, provide sufficient detail to distinguish unit training costs. It is conceivable that these estimates can be refined by the services."

Logistics Management Institute, 1993, p .1[2]

The results, shown in Figure II-8, are the only known data that attempt to estimate the amount of funds that support unit training. According to LMI's estimate, about $12.7 billion was allocated to unit training in FY 1993. The largest share ($5.3 billion or 42 percent) of the funds identified with unit training are allocated to the Air Force. This

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2 The data developed by the Logistics Management Institute on unit training by Service and on total OPTEMPO by Service were provided by the Director, Readiness and Training, OUSD (Personnel and Readiness). We appreciate the assistance provided by Michael A. Parmentier and Daniel E. Gardner of OUSD (P&R) and Steven Lieberman of LMI.

indicates, again, that the largest expense for training (unit training in this instance) is due to aviation; a figure that includes OPTEMPO for flying hours in all Services is given below.

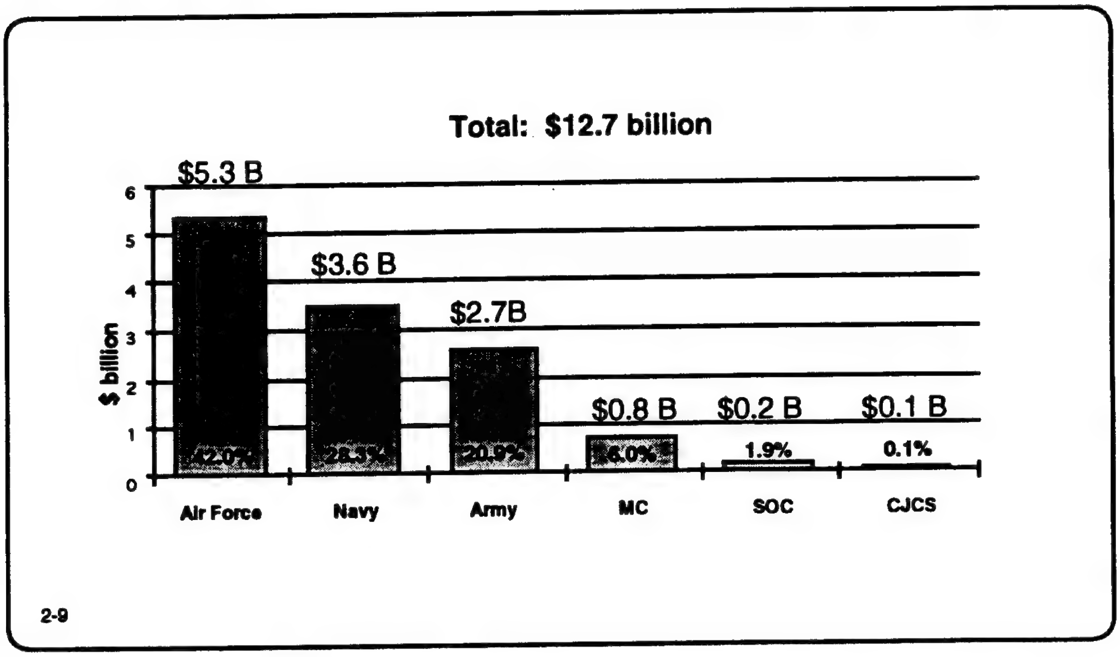


Figure II-8. Estimated Cost of Unit Training by Service, Special Operations Command and Joint Forces, FY 1993 (Source: Logistics Management Institute, 1993)

A major caveat: these numbers represent programmed funds. In O&M, more than in any other major budget category, local commanders have the authority to transfer funds from one Program Element to another. Hence, it is possible that the support for unit training can be greater than or less than that indicated in this figure, even if the estimated shares of programmed funds in support of unit training should happen to be exactly correct. For example, a commander who puts a high priority on a scheduled collective training event for which there are no remaining funds has the authority to divert money (e.g., from maintenance of equipment or real property to unit training) and can in this way exceed programmed expenditures. Another commander may find it impossible to put off certain maintenance for which he has insufficient funding, and can cancel certain training events to find a source for the needed funding. Thus, the true amount of support for unit training can only be known *ex post facto*. Neither the Comptroller nor any other agency in OSD has the means to track O&M expenditures on an ongoing basis. It would require a very time-consuming data call to the Services to find out precisely how much money was actually spent on unit training in any budget year. For the present, the informed judgments produced by LMI provide the best available assessment of unit training costs.

The amount of field training that each Service conducts each year is called OPTEMPO (Operating Tempo), expressed in terms of the average number of flying hours per aircraft, steaming days per ship, or miles traveled per vehicle. The costs of OPTEMPO include the costs of fuel, consumption of spare parts and maintenance-related activities associated with training. The costs of these activities for FY 1993-1995 were estimated by LMI from information submitted by the Services in the Program Objective Memorandum (POM) for FY 95-99. The total cost of OPTEMPO, by Service, for FY 1994 is about \$9.4 billion, an increase of \$2.9 billion (45 percent) over FY 1993 (Figure II-9). The Army is the largest Service in terms of personnel, but it accounts for less than 20 percent of total OPTEMPO dollars. The Air Force, with its costs for the use of aircraft, accounts for 39 percent of the total OPTEMPO budget.

	FY93	FY94	FY95
Army	\$1.9 B	\$1.8 B	\$1.8 B
Navy	1.5	3.1	2.9
Marine Corps	.1	.8	.8
Air Force	3.0	3.7	3.7
Total	6.5	9.4	9.3

Figure II-9. Cost of OPTEMPO, by Service, FY 93-95
(Source: Logistics Management Institute, 1993)

Another and larger estimate of OPTEMPO is provided by Angier, Alluisi, and Horowitz (1992) who used aggregated budget data for Service expenditures for operations, consumables, repairable spares, and maintenance. They estimate that OPTEMPO costs for FY 1991 were \$21.4 billion, as follows:

Flying hours (A, N, AF)	\$11.7 billion
Steaming days (N)	8.4
Vehicle miles (A)	1.3
Total	21.4

This amount is 2.3 times larger than the LMI estimate of \$9.4 billion for FY 94 and some explanation of the difference is needed. Since both studies used the same data sources (i.e., the Service POMs) the difference must be attributed to costs included in the

larger estimate (Angier et al.) that were not included in the smaller estimate (LMI). For example, Angier et al. (1992) included costs of repair and depot maintenance that are not included in the LMI estimate. We were not able to account for other items that could explain the different results of the two studies, even after contacting the authors. Obviously, the ad hoc nature of the two studies shows that there is a problem of defining the cost elements that should (or should not) be included in the costs of OPTEMPO and of identifying them in each report. We note, with pleasure, that this problem might not arise if only one report had been found. The absence of a periodic reporting requirement leads to the problem we observed both for knowing what the actual costs of unit training and OPTEMPO are and for being able to discern trends in these expenditures that may have significant impact on readiness.

Neither of these estimates includes certain other costs that are clearly relevant to OPTEMPO, such as transportation of equipment and personnel from home base to the exercise area and return (to the extent that this is not already included in the cost of fuel), ammunition expended during training, and the pay and allowances of personnel being trained. These are not trivial items and a case could be made to include them, or not, for various applications. But the critical point is that one has to be explicit about the costs that are included, with a definition of each cost element, together with an explanation of its relevance. Unless reliable and consistent data on the costs of OPTEMPO and unit training are reported regularly, it is difficult to believe that there can be an accurate understanding about the costs of training and simulation and of the influence of these various cost elements, if any, on significant outputs such as Service and joint readiness.

The Chairman of the Joint Chiefs of Staff is responsible for the joint Exercise Program that is estimated to cost about $425 million per year. About 75 percent of this amount is allocated to transportation of equipment and personnel for participation in exercises. A worthy purpose can be served to the extent that distributed interactive simulation provides a means to accomplish joint exercises while avoiding the costs of transportation, which constitute such a large fraction of the total costs of exercises.

Research and Development

Research and development on Training and Personnel Systems Technology (TPST) is reported in four functional categories (called "Congressional" categories):

Manpower and personnel

Education and training

Simulation and training devices

Human factors and safety

Data on programmed expenditures in these four areas, by Program Element and Project Number, are compiled each year by the Manpower and Training Research Information System (MATRIS), San Diego, California, an agency of the Defense Technical Information Center, Alexandria, Virginia. The total expenditure for TPST was $287 million in FY 1993 and $278 million in FY 1994 (Figure II-10). The largest expenditure among the four categories for these years was for Simulators and Training Devices: $122 million (42 percent) in FY 1993 and $125 million (45 percent) in FY 1994. Over the entire period, the Navy spent about half as much for R&D on simulation and training devices as the other Services.

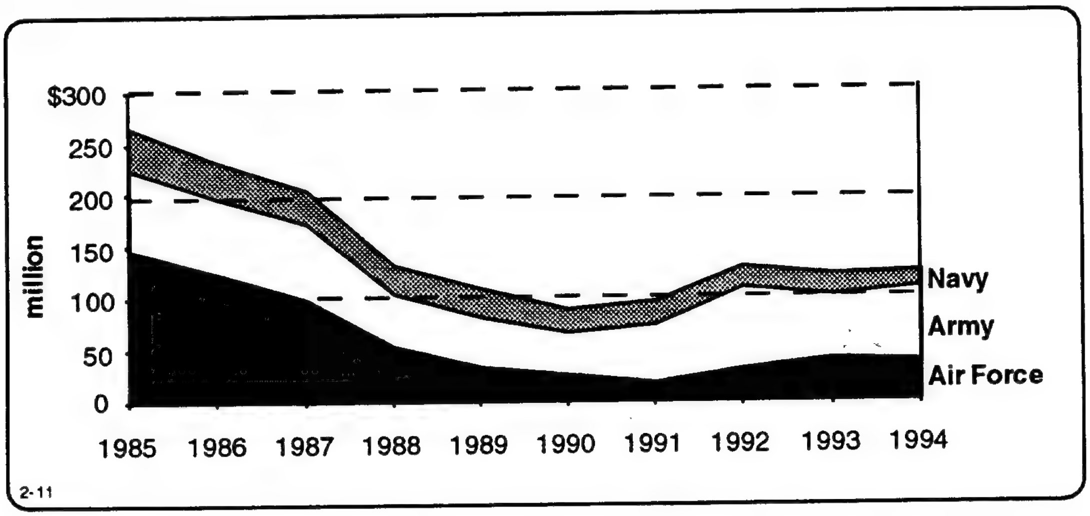


Figure II-10. R&D for Simulation and Training Devices, by Service, FY 1985–1994 (Source: MATRIS, 1993)

Total R&D for simulation and training devices declined to a low of about $88 million in FY 1990. This was due primarily to a reduction in the acquisition of simulators by the Air Force. The Army and the Air Force now spend close to the same amount ($65.6 and $58.5 M, respectively) while the Navy spends less ($18.7 M). (MATRIS, 1993)

We reviewed all projects reported by MATRIS in the two categories that deal with training: (1) Education and Training and (2) Simulation and Training. Work unit descriptions were examined to identify those concerned primarily with technologies relating to training equipment or methods of training and the agencies and funds assigned to each. The results are summarized in Figure II-11, while the details are shown in Appendix B.

	Training Equipment		Training Methods		Total (M)
Army	STRICOM[1]	$51.5 M	ARI[4]	$14.1 M	$65.6
Navy	NTSC[2]	16.6	NADC[5]	2.1	18.7
Air Force	TSSPO[3]	32.6	AL/HRAT[6]	22.2	54.8
TOTAL		100.7		38.4	139.1

1 STRICOM: Army Simulation and Training and Instrumentation Command, Orlando, FL

2 NTSC: Naval Training Systems Center, Orlando, FL, now Training Systems Division, Naval Air Warfare Center, Orlando, FL

3 TSSPO: Air Force Training Systems Special Program Office, Aeronautical Systems Division, Wright-Patterson Air Force Base, OH

4 ARI: Army Research Institute, Alexandria, VA

5 NADC: Naval Air Development Center, Warminster, PA

6 AL/HRAT: Air Force Armstrong Laboratory, Human Resources Directorate, Air Training Research Directorate, Mesa, AZ

Figure II-11. Funds Allocated to Development of Training Equipment and Methods of Training, by Agency, FY 1994 (Source: MATRIS 1993)

It is a matter of interest to observe that $101 million (72 percent) of the funds allocated to simulation and training in FY 1994 are assigned to the training equipment agencies of the Services (STRICOM, NTSC, and TSSPO) and that $38 million (28 percent) are assigned to the training research and development agencies (ARI, AL/HRAT, and NADC), i.e., agencies concerned with how best to use training devices.

On-the-Job Training

Although it is obvious that in order to achieve full proficiency some amount of on-the-job training is needed after completion of formal training at school, the effectiveness and costs of on-the-job training have received only limited attention. The Navy provides specialized training for certain jobs in two ways: at formal schools for periods of six to 37 weeks (depending on rating), or by on-the-job training in the fleet, without prior schooling. Both groups receive some on-the-job training before becoming eligible to take a written examination required for promotion to E-4 (third class). Weiher and Horowitz (1971) compared the effectiveness and cost of each type of training for the same job. The costs of on-the-job training include the costs of supervision, lower productivity of trainees, and pay and allowances of students while they are being trained; the costs of training at schools includes salaries of students and trainers as well as other expenses of running a school. Weiher and Horowitz found that those who have only on-the-job training take an average of 11.7 months (72 percent longer) to reach full proficiency (qualification to take the

promotion examination) compared to 6.8 months for those who attended Apprentice ("A") school; the comparable costs are $384 million (66 percent higher) for OJT and $231 million, for those who attended school (data for a six-month test cycle). These findings do not mean that school training can replace on-the-job training. However, because of the higher cost of on-the-job training, determination of an optimum mix of both methods of training, for particular jobs, would seem to be a worthy goal that has received little attention.

Not only is the cost of on-the-job training almost invisible, but it may even be said not to cost anything as long as manpower, when not at war, is available to provide OJT. Of course, the argument against this view is that there is an implied cost for personnel needed to conduct, or supervise, on-the-job training of new personnel, and who are not, therefore, able to perform their other duties. Low productivity of trainees, pay and allowances of trainees and supervisors, are other elements of the costs of OJT.

Gay (1974) developed a method of estimating the costs of on-the-job training in the Air Force, based on an application of modern human capital theory; investment in OJT is measured as the present value of the sum of positive differences between an individual's military pay and productivity (in dollars) over time. In a pilot study of Aircraft Maintenance Specialists, OJT was estimated to cost $6,600 per year (FY 1972) for trainees who also had attended Air Force technical school, which cost an additional $3,200. In this case, training of Aircraft Maintenance Specialists cost a total of about $9,800 over four years, of which OJT cost about two-thirds or twice as much as prior school training.

Shiells (1991) studied 13 non-technical Naval ratings that can be trained either at school or on-the-job. She found about the same level of performance for personnel trained both ways, with a tendency that graduates of longer courses (with a maximum of three months) performed better than graduates of shorter courses. In this study, effectiveness of on-the-job training was assessed by comparing the survival, promotion, and re-enlistment rates of personnel qualified on the job to those who qualify by attending apprentice ("A") school.

Even when on-the-job training is required to improve the skills learned at school, the operational environment is often not a congenial one for training. Operational assignments have priority over those related to training and the conditions needed for adequate training may not be available. Semb, Ellis et al. (1993) found that very few shipboard petty officers receive any training or information on how to conduct on-the-job training. While over 50 percent of supervisors reported that they used appropriate OJT

techniques, at least 20 percent said that they do not and another 30 percent are not as effective as they could be. Since these data were collected by means of a questionnaire, these findings may be viewed as optimistic and actual performance of OJT is probably poorer than is reported here. Figure II-12, taken from Gay and Nelson (1974), is a notional representation of the fact that both training at school and on-the-job have real costs and that the returns that new personnel make to the military service become positive only after some period of learning. The cost of training and length of the period of learning is a function of the complexity of various jobs; formal training lasts more than 18 months for some electronics and nuclear technicians occupations. The costs of on-the-job training include the pay and allowances of students and of those who supervise their work as well as damage that novices may cause to tools and equipment, less the positive contribution that their increasing productivity brings to the job.

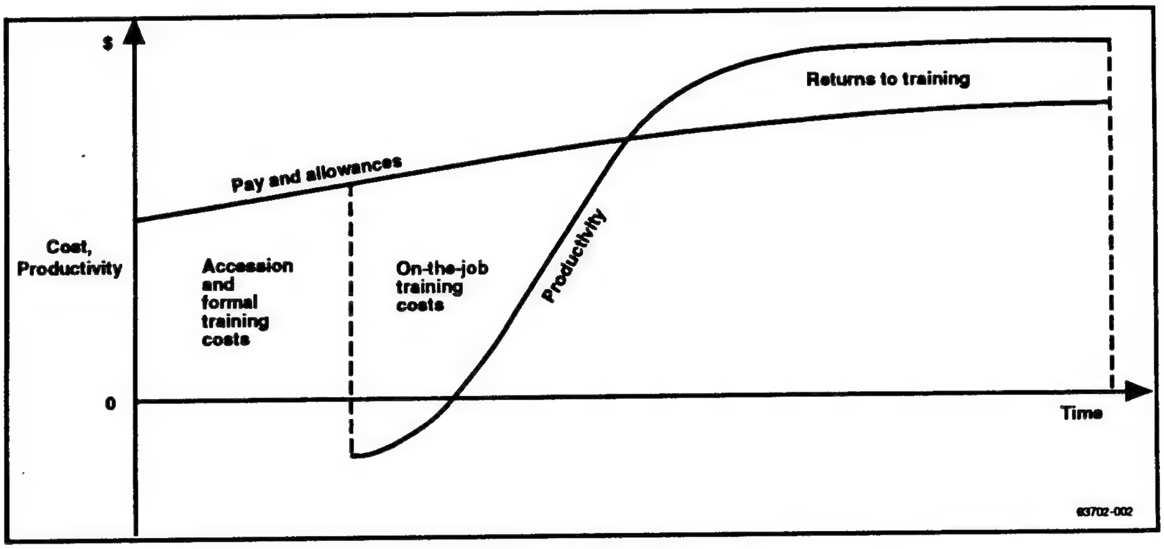


Figure II-12. Costs of Formal and On-the-Job Training and Returns to Training Due to Productivity (Source: Gay and Nelson, 1974)

Quester and Marcus (1984) compared the cost of training Navy technicians either at school or on-the-job in 12 occupations and their productivity over four years. Net productivity of trainees was rated by supervisors for four points in time (1 month, and 1, 2, 4 years) as a percent of the output of an average specialist with four years of experience in that occupation; net productivity is an estimate of the contribution to work minus the loss in production of experienced personnel who train and supervise trainees. In all occupations (e.g., Aviation Machinists' Mate, Radioman, Electronics Technician), personnel trained at school were more productive (by an average of 27 percent) than those trained on the job (Figure II-13). For most occupations, graduates of formal schooling are more cost-

effective than those trained exclusively on the job; the reverse is true for a few less technical jobs such as Electronics Technician, Radiomen, and Machinist's Mates. School training would appear to be even more cost-effective if data were collected to cover longer careers than the first enlistment (i.e., more pay-back).

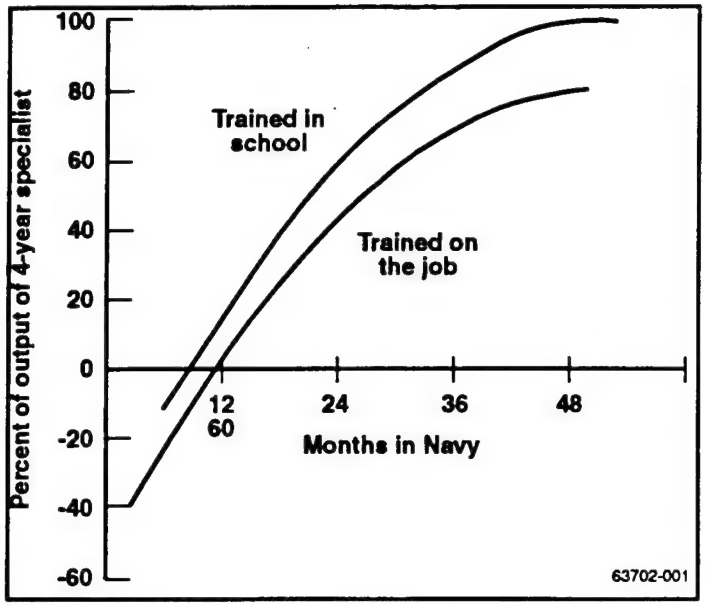


Figure II-13. Productivity Growth for Electricians' Mates in the First Term (Source: Quester and Marcus, 1984)

New technology, such as distance learning, interactive courseware, multi-media training devices, computer-based instruction, as well as portable, sophisticated electronic job aids for maintenance (e.g., Vu-Man) can significantly improve the effectiveness of the informal type of training that occurs in operational units; interactive videodisc instruction reduces training time by 30 percent (Fletcher, 1990); Vu-Man cuts the time of technical inspection of equipment by 50 percent (Deutch, 1994). The collection of reliable data on the cost and effectiveness of on-the-job training with current and new tools is a difficult task but it is still needed to assess the utility of this type of training.

For reasons that are not obvious, OJT remains a generally overlooked type of training whose effectiveness could be improved and whose current costs are not known.

Discussion

Data on the costs of simulation and training that have been presented in this chapter are useful but incomplete. Data on the cost of individual training in institutions are considered to be reliable and valid. They are reported regularly in the annual Military Manpower Training Report, so that trends in the number of people trained in various types of training and their costs are known; the cost categories used in this report have been

defined, are used consistently, and have an average error of less than one percent (Elder et al., 1986, 1989). A similar situation exists in two other areas: the content and cost of the research and development program on Training and Personnel Systems Technology (reported by the Manpower and Training Research Information System, or MATRIS, an agency of the Defense Technical Information System); and on the procurement of military trainers and simulators (a commercial market survey produced from time to time by Frost & Sullivan Market Intelligence, New York, N.Y.). Information contained in the latter survey is compiled from information published by the Department of Defense on prime contract awards and on summaries of planned procurements provided by the Services. Frost & Sullivan provided a convenient and quick way to collect information that would otherwise require an effort beyond our means for this study. It is not, obviously, an authoritative document issued by the Department of Defense.

Little documentation of this quality applies to our other data on the costs of training and simulation. All of our sources are the result of ad hoc efforts, and these reports do not always identify or define the cost elements in a consistent (or even clear) manner; some of our data were provided by briefing material or informally by professional colleagues. This makes it difficult, and perhaps unwise, to compare or combine data from different sources in order to analyze the cost and effectiveness of various types of training and simulation even though such analyses are vital for developing policy to guide research on training and simulation towards areas of maximum pay-off. The reader is therefore warned to use our cost data with care even though, we believe, they are the most extensive currently available on simulation and training. It is also difficult to comprehend how policy on the technology most relevant to simulation and training, and to the procurement of equipment and procedures for the most effective use of simulation and training can be developed meaningfully in the absence of more complete and reliable, consistent and comparable data on the costs of these activities.

Mindful of the qualifications that must apply to the data we found, we will examine these costs in two ways:

(1) Annual expenditures

(2) Type and location of training.

Annual Expenditures

The cost data shown in previous figures cover different periods of time. In Figure II-14, these costs are reported as annual expenditures for RDT&E, initial

Type of Expenditure	Amount[1]	Period	Source
RDT&E			
Simulators for weapon systems	$0.336	FY91–97	Frost & Sullivan (1993)[2]
Technology			
training equipment	0.101	FY94	MATRIS (1993)[3]
training methods	0.038	FY94	MATRIS (1993)[3]
Modeling and simulation			
Joint commands	0.019	FY 91–92	IG (1993)[4]
DMSO	0.073	FY 93–94	DMSO (1994)[5]
ARPA	0.103	FY 92–97	ARPA (1993)[6]
Initial investment			
Procurement of simulators		FY 91–97	Frost & Sullivan (1993)
Aviation 0.800			
Non-system devices 0.243			
All others 0.057			
	1.100		
Models and simulations	NA		
Military Construction	NA		
Operating and Support			
Individual training in institutions	14.4	FY94	MMTR (1993)[7]
Individual training in units	NA		
Collective training in institutions	NA		
Collective training in units	12.7	FY93	LMI (1993)[8]
OPTEMPO	9.4 21.4	FY93 FY91	LMI (1993) Angier et al. (1992)[9]
Joint exercises	0.425	FY 94	Briefing material
Simulator maintenance	0.369	FY 91–97	Frost & Sullivan (1993)

[1] Amount, in billions, for year cited or average of years noted.
[2] Frost & Sullivan (1993)
[3] Manpower and Training Research Information System (1993)
[4] Inspector General (1993)
[5] Defense Modeling and Simulation Office (1994)
[6] Advanced Research Projects Agency (1993)
[7] Military Manpower Training Report, FY 94 (1993)
[8] Logistics Management Institute (1993)
[9] Angier, Alluisi, and Horowitz (1992)
NA: Not Available

Figure II-14. Estimated Annual Expenditures for Training and Simulation, in Terms of RDT&E, Initial Investment, and Operating and Support of Training

investment, and operating and support, either for the year noted or as an average of the years for which costs are available; the format follows the cost element structure for defense training developed by Knapp and Orlansky (1983) and other studies of defense costs. One is advised not to add these costs since there are the possibilities both of redundancy and incompleteness. Nevertheless, it is clear that the annual costs of training (operating and support) are in the tens of billions, procurement of training equipment (initial investment) in the billions, and research and development on training equipment and training methods, and on modeling and simulation (including distributed interactive simulation) also in the order of millions; the latter costs, while small in comparison, may be incomplete. We were not able to find cost data on individual training in units (which could be large), or on investment costs for modeling and simulation and military construction for training, or on collective training in units. Whether these costs include costs for transportation to training sights, ammunition, and other incidental costs related to training is unknown.

Type and Location of Training

Figure II-15 follows the paradigm suggested by General Paul Gorman in Chapter I and reports the costs of training shown in the preceding figure on the basis of type of training and where training occurs. Individual training at institutions cost $14.4 billion in FY 1994; collective training in units cost $12.7 billion in FY 1994, while OPTEMPO, also in units, is estimated to cost $9.4 billion (FY 1993) or $21.4 billion (FY 1991), according to two different sources for this data. We have determined that the larger figure includes costs of depot maintenance that are not included in the smaller figure; but this cannot account for all of the large difference. It is also important to note that the costs of collective training in institutions and of individual training in units are not now available. The raw data undoubtedly exist but there are no present means to define the relevant cost elements and locate their sources, other than to commission another ad hoc study. Nor is there a report that compiles such costs periodically to develop trends in expenditures and provide a basis for oversight and policy development. As was pointed out previously, the cost data on unit training and OPTEMPO are the result of ad hoc efforts that require clarification to be truly useful. Data on RDT&E and on initial investments for training are not included in this figure.

Where Training Occurs

Who is trained	Institution	Unit
Individual	By service, FY 94[1] Army $5.4 B Navy 4.5 Marine Corps 1.3 Air Force 3.2 14.4 By type, FY 94[1] Recruit $1.2 B Officer acquisition .5 Specialized skill 4.1 Flight 2.2 Professional development .9 OSUT (Army)[7] .3 14.4	Not available: Individual (on-the-job) training in units for those trained only on the job, job familiarization for those trained at schools, and training for those assigned jobs that do not match their MOS[6]
Collective	Army Combat Training Centers, FY 95 .5 B[5] Other data not available	Unit training $12.7 FY 93[2] OPTEMPO 9.4 FY 93[2] 21.4 FY 91[3] Joint exercises 0.425 FY 94[4]

1 MMTR (1993).
2 LMI (1993).
3 Angier, Alluisi, and Horowitz (1992).
4 Briefing Estimate.
5 AUSA (1994); about one-third of this total is for transport to and from the training center (Fig. II-16).
6 CBO (1994) estimates 6-10 percent mismatch between job and MOS in the Army, FY 1993 (p. 32).
7 OSUT: Army One-Station Unit Training; combines Recruit and Specialized skill training.

Figure II-15. Estimated Annual Expenditures for Training, by Type of Training and Where Training Occurs (excludes RDT&E and initial investment)

The significance of including other costs, such as for transport, pay, and ammunition, may be illustrated by the Angier et al. (1992) estimate of the costs of one field training exercise by an armored battalion at the National Training Center (Figure II-16); the total cost is estimated to be $16.25 million. A visit by an armored battalion to the NTC takes about one month. Half of that time is spent in the actual exercise, while the rest of the time is spent packing and unpacking equipment and traveling. Transport accounts for 31 percent and pay and allowances of the OPFOR for 19 percent of the total cost of one rotation; these data include but do not specify separately the cost of ammunition; pay and allowances of the BLUFOR, the battalion being trained, are not included. It is helpful to know precisely what costs are or are not included. In saying so, we do not suggest that there is one right or best way to present cost data on training because the particular analysis should dictate the costs that are considered to be relevant to the analysis. Our inability to estimate the overall costs of unit training and OPTEMPO is a result of uncertainty about the composition of the data we were able to find.

Transport (base to NTC and back)	$ 5.0 million
Tools and spares	.5
Range decontamination	.25
OPFOR OPTEMPO and ammunition	4.5
Blue OPTEMPO and ammunition	3.0
OPFOR pay and allowances	3.0
TOTAL	16.25

Figure II-16. Cost of One Exercise at the National Training Center (Source: Angier et al., 1992, p. A-7)

FINDINGS

1. Data on the costs of simulation and training and of its major components are not now reported in any regular or consistent fashion. Two major exceptions are the costs of individual training at institutions, which are reported in the Military Manpower Training Report and the costs of Training and Personnel Systems Technology, which are reported by the Manpower and Training Research Information System. Estimates of the costs of collective training in units, OPTEMPO, joint exercises, procurement of simulators, R&D on modeling and simulators were found in some ad hoc studies. Apart from the fact that these costs are not reported regularly, nor are readily available, such reports are often not

clear about the cost elements that are included or are explicitly excluded. Important data on training costs that could not be found include the costs of individual training in units (on-the-job training), collective training in institutions, Service exercises, the procurement of simulators (a commercial source was used for these data), and modeling and simulation. All of the raw data on such costs undoubtedly exist somewhere within the Services and in various data banks; however, they are not reported regularly in a form useful for evaluating the cost and effectiveness of various methods of simulation and training, and for policy decisions on developing the required technology and on investing in the most cost-effective simulation and training systems.

2. The annual cost of individual training at institutions is estimated to be $14.4 billion (FY 1994). This value comes from the Military Manpower Training Report, an annual report that is clearly reliable. The annual cost of collective training in units is estimated in one report to be $12.7 billion (FY 1993). OPTEMPO (operating tempo in units) is estimated in one study to cost $9.4 (FY 1993) and $21.4 billion (FY 1991) in another. These values cannot include the same cost elements; but, except for one element (depot maintenance), we were not able to explain the reasons for such widely different estimates.

3. The cost of procuring simulators is estimated to be about $1.2 billion per year (FY 91–97); RDT&E for simulators, simulations, modeling and methods of training is estimated to be about $.6 billion per year (FY 91–97). These estimates come from different sources and need further examination.

4. Aviation accounts for the largest expenditures for training when estimated by the costs for procurement of simulators, initial pilot training, or OPTEMPO for flying hours. There is little evidence that research and development on training is concentrated in these areas of high pay-off. A similar observation applies to research and development on distributed interactive simulation, where large costs for future procurements are likely to occur.

5. On-the-job training is a neglected area with regard both to its effectiveness and its cost. Although all personnel in all military occupational specialties receive some on-the-job training, there is reason to believe that its costs are obscure (because of the efforts required to supervise trainees) and that there is room to improve the efficiency of this method of training (by the use of new technology, such as distance learning, computer-based instruction, and advanced job-aiding devices).

III. COST AND EFFECTIVENESS OF SIMULATORS

Training in a simulator is known to improve performance in that simulator. If the training transfers, i.e., if the skills learned in a simulator can be performed in the actual equipment, then the simulator is an effective training device. If the skills do not transfer, then the improved performance in the simulator merely means that the trainee has learned to master the simulator and its quirks. What we really want to know is the extent to which training in a simulator improves (or diminishes) performance in the actual equipment for which the simulator is supposed to provide training.

Many studies show that simulators can provide cost-effective training. Briefly, this means that simulators train as well as actual equipment but cost less to buy and use. But this does not apply to all tasks, all types of training, and to simulations. For example, it has been determined that the SIMNET system has the capability to train tank crew members on about 35 percent of the tasks specified in the Army Training Evaluation Program (ARTEP) (Burnside, 1990). This is a consequence of the design, technology, and cost targets set for the development of SIMNET. Therefore, the effectiveness of SIMNET should be evaluated on the basis of how well personnel trained in SIMNET can perform these 35 tasks in tanks. An expectation that trainees should be able to perform more or all of the ARTEP tasks could easily show that SIMNET has low effectiveness, but that would be an erroneous conclusion. An enlarged standard could be set for the Close Combat Tactical Trainer (CCTT), an advanced version of SIMNET where it has been determined that the new device can provide training on about 60 percent, but not 100 percent, of all ARTEP tasks (Noble and Johnson, 1991). Clearly, the remaining 40 percent of the ARTEP tasks could be trained either in the actual tank or in another simulator designed for that purpose. It is often said that using the actual equipment is the best way to train but this is clearly a short-sighted view. In some cases this is simply too dangerous for a novice; in others, the equipment is so complex that some other way of training must precede exposure of a trainee to the actual equipment; that is why the military uses trainer aircraft and simulators.

Two issues dominate the choice between using a simulator for training and using actual equipment: the effectiveness and the cost of using the simulator for training as compared to the effectiveness and cost of using the actual equipment for the same purpose.

Effectiveness means the level of performance achieved by use of the simulator to obtain the skills specified as needed to operate the actual equipment or, in the case of a maintenance training simulator, to maintain complex equipment. Cost should mean all costs, on a life cycle basis; some studies examine only the procurement costs or the operating costs. Figure III-1 shows the possible outcomes in a comparison of the cost and effectiveness of a simulator versus that of actual equipment for training and, as a consequence, the decision that should be made for each outcome.

		EFFECTIVENESS		
		LESS	SAME	MORE
COST	LESS	?	+	+
	SAME	–	?	+
	MORE	–	–	?

+ ADOPT
– REJECT
? UNCERTAIN

Figure III-1. Decision Diagram for Evaluating the Effectiveness and Cost of Two Methods of Training

Studies that have evaluated the cost-effectiveness of flight simulators and maintenance simulators are summarized below. Other types of simulators, such as gunnery trainers, have also been evaluated but primarily for effectiveness and not cost; such studies do not yield a coherent picture and are not considered here. To the best of our knowledge, the cost-effectiveness of other types of simulators has not been systematically evaluated. Because the Close Combat Tactical Trainer (advanced SIMNET) is a large procurement, a cost and operational effectiveness analysis will be, but has not yet been, conducted. Many evaluations of flight simulators and maintenance simulators have been performed.

Flight Simulators

Except for aircraft designed specifically for use as trainers, most aircraft are designed to perform some operational requirement, such as air superiority or transport. Their use for training is an ancillary function. Thus, it is relevant to compare the operating costs of using a combat aircraft or a simulator of that aircraft for training purposes, and not the RDT&E or procurement costs that are directed towards combat rather than training; the costs of RDT&E and procurement would be relevant if we were evaluating an airplane designed primarily for purposes of training. A comparison of the operating costs of 42 flight simulators and aircraft is shown in Figure III-2.

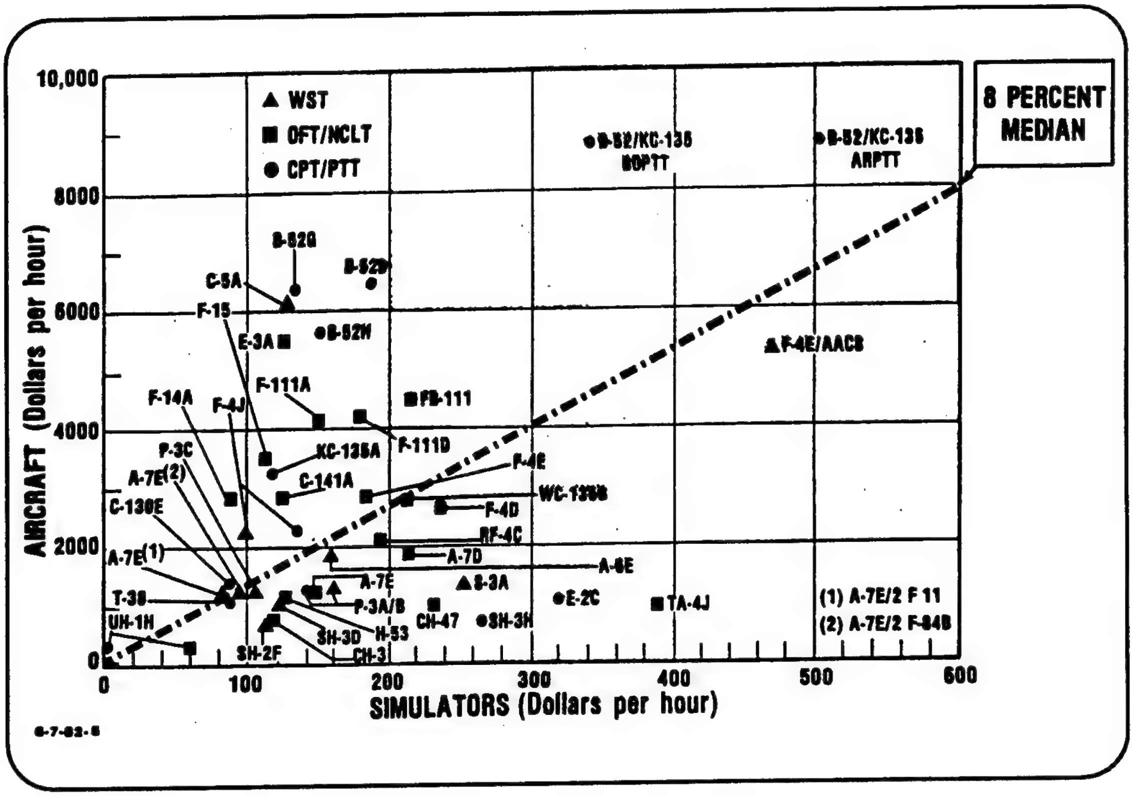
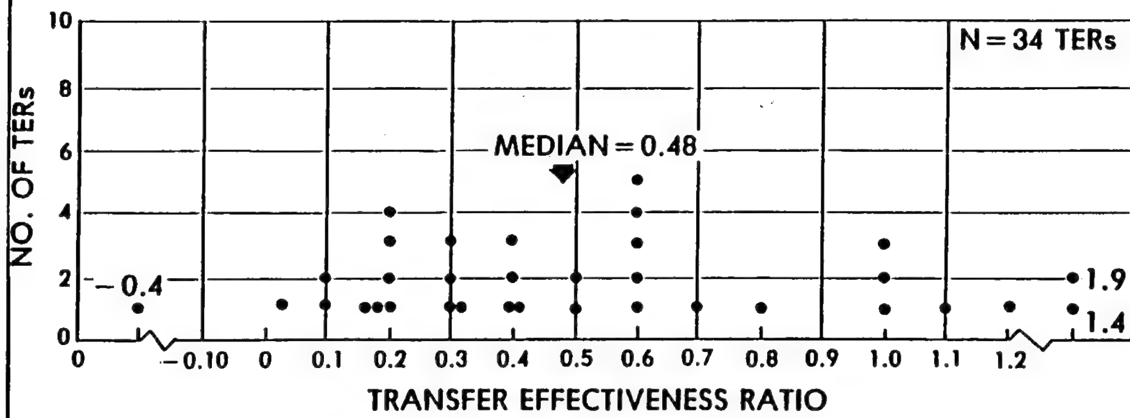


Figure III-2. Variable Operating Costs per hour for 42 Flight Simulators and Aircraft (Source: Orlansky, Knapp, and String, 1983)

Variable operating costs include the costs of fuel, lubricants and spare parts needed to maintain equipment, as a function of its use. The data show that the cost of operating a flight simulator varies between 5 and 20 percent that of its comparable airplane. The median value of several such assessments is about 10 percent (Orlansky and String, 1977; Orlansky, Knapp, and String, 1983).



$$\text{TER} = \frac{A - A_S}{S}$$

A	=	Aircraft Time, Without Simulator
A_S	=	Aircraft Time, After Simulator
S	=	Simulator Time

3-4

Figure III-3. Transfer Effectiveness Ratios from 22 Studies (Source: Orlansky and String, 1977)

The Transfer Effectiveness Ratio (TER) compares the amount of training time needed to perform a specific task in an airplane either (1) after training only in the airplane or (2) after prior training in a simulator. The TER describes the amount of flight time saved, as a function of the time spent in a simulator on the same task. A ratio of one would mean that one hour spent in a simulator saves one hour in the airplane. The median of 34 TERs compiled from 22 studies is 0.48; this means that about one-half hour is saved in the air for every hour of prior training on the same task in a flight simulator (Figure III-3). Positive transfer from simulator to aircraft is also reported by Hays et al. (1992) in a paper that summarizes the effectiveness of flight simulator training found in 15 more recent studies.

Since the use of a simulator for training (1) results in flight performance that is about the same as that produced by the use of an airplane, (2) saves flight time, and (3) costs only about ten percent of the cost of an airplane, it follows that a flight simulator is a cost-effective method of flight training by a factor of about five. Considering that the

technology of flight simulators (e.g., computers, visual, and motion systems) has improved beyond that contained in these studies, and that their costs have also been reduced, it is reasonable to believe that the cost-effectiveness of currently available simulators has probably increased.

Only a few studies have examined the amortization of flight simulators, i.e., how long it takes for the savings attributed to their use to pay for the cost of procuring them. Two studies suggest that the cost of procuring military flight simulators can be amortized in about two years (Figure III-4). A similar study shows that a major airline amortized the cost of five flight simulators in less than one year. The main reason for the difference may be found in the utilization rate; commercial airlines use their simulators for almost 24 hours a day compared to 8 to 16 hours a day for the Services.

Simulator	Procurement Cost	Savings per Year	Time to Amortize Costs [1]
Coast Guard, HH-52A HH-3F	$ 3.1 M	$ 1.5 M	2.1 years
Navy, P-3C	4.2 M	2.5 M	1.7 years
Airline	17.5 M	25.3 M	8.3 months

[1] Procurement cost/savings per year

Figure III-4. Amortization of Flight Simulators (Source: Orlansky and String, 1977)

Although actual equipment is widely used for training maintenance technicians, simulated maintenance equipment and test bench equipment have certain advantages: a wider variety of malfunctions can be represented; malfunctions can be "installed" more readily; critical parts can be exposed or blown up for purposes of training; and, not least, performance can be measured. Some maintenance simulators look almost exactly like the actual equipment.

The studies summarized in Figure III-5 show that students trained on maintenance simulators can perform maintenance tasks about as well as those trained on actual

equipment. A few studies provide data on student time savings, if any; when reported, time savings due to the use of simulators are of the order of 25 to 50 percent. One could argue that maintenance personnel trained on simulators should perform better than those trained on actual equipment. The reason is that simulators, although artificial, can provide cues to malfunctions, and hints to diagnosis of faults that are not available in actual equipment and these hints make it easier to diagnose real malfunctions when actually needed. However, the current data do not support this proposition.

SIMULATOR	COURSE	COURSE LENGTH (STANDARD)	NO. OF SUBJECTS	COMPARISONS: SIMULATOR TO ACTUAL EQUIPMENT					
				EFFECTIVENESS				ATTITUDE TO SIMULATORS	
				POORER	SAME	BETTER	TIME SAVINGS	STUDENTS	INSTR.
Generalized Sonar Maintenance Trainer	Sonar maintenance (special course)	4 days	9		•		22%	+	
	Intermediate General Electronics	4 weeks	20		•				
EC II	APQ-126 Radar		17					+	
	Mohawk Propeller System	3 hrs	33			•			
	Hydraulic and Flight Control	32 hrs	13		•	•		+	–
	Engine, Power Plants and Fuel	24 hrs	13	•	•			+	–
	Environmental/Utility System	32 hrs	9		••			+	–
	APQ-126 Radar	60 hrs	15		••			0/+	0/+
	Pilot Familiarization, T-2C	10 hrs	6						+
	Flight Officer Familiarization, TA-4C	11 hrs	30						+
Generalized Maintenance Training System	SRC-20 UHF Voice Command System		20				ABOUT 50%	+	
	SPA-61 Radar Repeater	16 hrs	10					+	
Fault Identification Simulator	Hagen Automatic Boiler	5 wks	16		•		ABOUT 50%		
6883 Converter/Flight Control Systems Test Station	F-111 Avionics Maintenance	6 days	56		•			+	0/+

Figure III-5. Studies on the Effectiveness of Maintenance Simulators (Source: Orlansky and String, 1981)

Computer-Based Instruction

Computer-based instruction is used for training on many jobs in the military services and industry and for education at all levels from kindergarten to graduate school. No effort will be made here to evaluate the growing capability of what is sometimes called

"high-tech learning." There is a very large literature on this subject. Here, we briefly summarize a few major substantive findings of interest to military training:[1]

1. Computer-based instruction saves about 30 percent of the time students need to complete a course, compared to conventional instruction.
2. Interactive videodisc instruction raises performance of 50th percentile students to about the 70th percentile achievement level.
3. The average cost of interactive videodisc instruction is about 40 percent that of conventional instruction.

Since current computers are easily transportable and their costs have been sharply reduced, they have high value for individual training in institutions as well as in units; their use for collective training also appears attractive.

Figure III-6 summarizes the findings of studies that have reported data on the cost-effectiveness of flight simulators, maintenance simulators, and computer-based instruction.

EFFECTIVENESS	FACTOR	SAVINGS OR COST		
		FLIGHT SIMULATOR	COMPUTER-BASED INSTRUCTION	MAINTENANCE SIMULATORS
ABOUT THE SAME	STUDENT TIME SAVINGS	50% OF SIMULATOR TIME	30%	20–50%
	ACQUISITION COST	30–65%	?	20–60%
	OPERATING COST	10%	?	50%
	LIFE-CYCLE COST	65%	?	40%
	AMORTIZATION	2 YEARS	?	4 YEARS

Figure III-6. Summary of Findings on the Effectiveness and Cost of Flight Simulators, Computer-Based Instruction, and Maintenance Simulators

1 Fletcher (1990), Fletcher and Orlansky (1989), Spencer (1991), Orlansky and String (1977), Kulik and Kulik (1986), Kulik et al. (1986)

These simulators are as effective for training as the use of actual equipment and cost less to own and to operate. Students take less time to master lessons when they are trained with simulators than with actual equipment; the average time savings is about 30 percent. The acquisition cost of simulators can be amortized in two to four years. Most of these findings are based on studies of initial rather than advanced training.

Discussion

Flight simulators, maintenance simulators, and computer-based instruction are demonstrably cost-effective methods of training, compared to the use of actual equipment or, in the case of computer-based instruction, conventional classroom instruction. The data needed to support this finding are robust and are derived from about 100 studies of simulators and hundreds more for computer-based instruction.

Nevertheless, it is important to understand what these findings do and do not mean. All evaluations of cost-effectiveness reported here are based on data for individual training in institutions. Further, they deal with initial rather than advanced training. Demonstration of their cost-effectiveness in this environment does not necessarily extend to advanced individual training or to collective training in any place.

Even if a simulator is equally effective in all environments, the costs of its use will vary as a function of its utilization (i.e., hours per day), the support provided for meaningful training (instructors and maintenance personnel), and the tasks for which it provides training. The conditions of unit training differ markedly from those at a school with respect to full-time availability of instructors and maintenance personnel, differing priorities for training, and the attention given to, or even the existence of, training plans for guiding what is supposed to be learned. It is difficult to believe that training, even if effective, can be performed as efficiently (i.e., at the same cost) in units as in schools. Collective training at an institution for personnel assigned to a unit entails the costs of transporting personnel and equipment from the unit to the school or field exercise facility and of their support while there, as well as the costs attributed to their not being able to perform their regular jobs while away from the unit. These considerations, depending on how they weigh in the outcome of any specific case, can easily change the cost-effectiveness of a method of training as its venue changes. This is why flight simulators—expensive devices—can be cost-effective for training at institutions but not in units, where they would otherwise be a highly useful asset. If the cost of simulators could be reduced, the outcome might favor their use in units. This appears to be the case for "unit training devices" now being

developed by the Air Force (described more fully in Chapter IV); these devices are less expensive than flight simulators and are computer-based, part-task trainers that can be easily modified to provide several different types of training in units.

In contrast, on-the-job training is not only a necessary type of training but it can be performed only in units. Except for jobs that require little skill (e.g., data processing technician, mess management specialist), it is not, however, a cost-effective method of training because the newly qualified students cannot perform their assigned tasks well, create errors, require supervision, and are placed in an environment that is not optimized for training. The trend to "embedded training," that is, the use of training features built into actual equipment, provides simulated targets and a performance-recording capability that supports individual and collective training in operational units.

It is understandable, but not necessarily prudent, to favor the use of simulators that train as well as actual equipment but cost less to procure and use. At issue, fundamentally, is the purpose of using simulators for training: to train as well as or better than is possible with actual equiment. The purpose of military training—and of the military establishment itself—is not to save money (or to make a profit). Its purpose is, clearly, to win wars. Military weapons are always justified in terms of better performance, preferably at no increase in cost, but at greater cost if necessary. The same paradigm should apply to simulators where the criterion, at least for military application, should be to provide superior performance to match the superior performance of advanced weapons. The current paradigm that supports the acquisition of simulators that train as well as actual equipment at less cost is short-sighted. We should change the paradigm so that training matches the one that applies to military weapons: improved performance at no increase in costs.

Figure III-7 shows the types of simulators and simulations that can be used for individual or collective training in institutions or in units. With some exceptions, one may observe that more costly simulators tend to be located at institutions rather than in units. This is a way of insuring more utilization and technical support than could occur in units. The reverse is also true: units can afford to use (or are offered) less complex and less costly simulators than are used in institutions. Two current trends are apparent: reductions in the cost of electronic equipment make it increasingly reasonable to use certain trainers in units, e.g., unit-training devices and embedded trainers. The other trend is that less expensive computing equipment as well as high-capacity communications can now support distributed interactive simulators for collective training in units. More powerful technology

at reduced cost favors the use of advanced simulators for collective training in units but cost-effectiveness evaluations to support this application remain to be conducted.

Where Training Occurs

Type of Training	Institutions	Units
Individual	flight simulators maintenance simulators computer-based instruction part-task trainers	on-the-job training computer-based instruction embedded trainers unit training devices part-task trainers
Collective	wargaming ENWGS, CBS, ACAAM crew training simulators networked simulators SIMNET, CCTT field training on instrumented ranges National Training Center Red Flag Marine Corps 29 Palms	command-post exercises/ combat models field exercises component and joint training Distributed Interactive Simulation STOW, MDT2 embedded trainers

ENWGS	Enhanced Naval War Gaming System
CBS	Corps Battle Simulation
ACAAM	Air Courses of Action Assessment Model
SIMNET	Simulator Networking
CCTT	Close Combat Tactical Trainer
STOW	Synthetic Theater of War
MDT2	Multi-Service Distributed Training Testbed

Figure III-7. Types of Simulators and Simulations That Tend to Be Used for Individual or Collective Training in Institutions or in Units

FINDINGS

1. Studies that have examined both the cost and effectiveness of simulators for training were found only in three areas: flight simulators, maintenance simulators, and computer-based instruction. The utility, i.e., the cost-effectiveness, of these devices for training is supported by extensive data. When students are tested on actual equipment, training with these simulators is as effective as training on actual equipment. The costs of using a simulator are always less than that of using actual equipment; operating costs range from about 8 to 50 percent that of actual equipment, depending on the type of simulator and

actual equipment being examined. Acquisition and life cycle costs of simulators are about half that of actual equipment. The magnitude of annual savings permits the cost of these simulators to be amortized in from 2 to 4 years.

2. While simulators are demonstrably a cost-effective method of training for certain tasks, this does *not* mean that actual equipment should not also be used for training. The central issue is to determine the optimum combination of simulators and actual equipment for training on the basis of effectiveness and overall cost. This will vary, of course, by type, complexity, cost of the simulator, and the tasks for which the simulator is used compared to the use of actual equipment. Issues of this type, which are fundamental to a rational choice for training, have barely been examined. On the whole, only the cost-effectiveness of simulators for initial training at institutions has been examined; the results favor the use of simulators in institutions. This type of evaluation has not been conducted for the use of simulators in all other types of training, i.e., individual training in units and collective training in institutions and in units.

3. The paradigm used to select simulators, rather than actual equipment for training, is a limited one: equal effectiveness at less cost. That is contrary to the rule generally observed for new weapons and advanced technology where greater effectiveness, even at greater costs, is an accepted paradigm. Greater effectiveness for our weapons is always preferred and is a premium in design, in order to counter the numerical superiority of an enemy and to reduce American casualties. More effective weapons generally rely on leading edge technology, are not easy to achieve and hence the acceptance of greater costs for marginal, but critical improvements. High technology weapons need not be expected to perform at their superior capabilities unless personnel trained to operate them can also perform at higher levels of effectiveness. Efforts to develop and to use simulators for training that provides increased effectiveness, with little or no increase in costs is a clearly desirable, although generally neglected, goal for simulators to be used for training.

IV. SERVICE EXPERIENCE WITH SIMULATION

This chapter describes an effort to identify the factors that may account for the success or lack of success in the use of simulations by the Services. All Services were approached with a request to identify examples of the successful application of simulations as well as examples in which problems had been encountered. The purpose of this effort, it was explained, was to identify features of successful simulations that could be incorporated or enhanced in future developments and, in the case of problems, to suggest ways to improve the design and use of new simulations. Information was solicited from the human resources laboratories, training commands, and simulation and training device development agencies. Access to the training and operational commands was helped by the participation of retired officers of all Services. Sampling was opportunistic rather than rigorous; with few exceptions, those contacted tended to be helpful and provided useful information.

We were able to identify simulations that our respondents regarded as successful. No "unsuccessful" simulations were volunteered or could be elicited; however, various types of problems were found. Below, we list simulations that were reported by each Service as either "successful" or having "problems." Some simulations are categorized as "undetermined" because data on their effectiveness are not yet available; most of these are current development programs for which expectations are high.

ARMY SIMULATIONS[1]

We list below the simulations reported by Army personnel.

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1 Most of the information in this section was gathered by Lt. General Frederic J. Brown, USA (Ret.).

Successful Simulations

Multiple Integrated Laser Engagement System (MILES)[2]

Success due to good instrumentation, supported by careful development of after-action review procedures, and use of trained observer controllers at the National Training Center

Conduct of Fire Trainer (COFT)[3]

Development of COFT was preceded by identification of 64 tasks, conditions and standards determined to be critical to crew proficiency in Armored Fighting Vehicles. Success attributed to development of a training program with a simulator, rather than only to a gunnery trainer.

National Training Center (NTC) and other Combat Training Centers (CTC)

Accurate performance measurement provides critical information that improves training effectiveness.

Simulators with Problems

Rifle marksmanship on instrumented range (TRAINFIRE)

Inadequate management of funds for construction and allocation of terrain for use of TRAINFIRE. Provided capability for shooting at an approaching enemy whereas most combat targets move laterally.

Improved Tank Training Ammunition

Thermal and light blooming effects of Service ammunition were not recognized in time because safety considerations precluded actual training with an opposing enemy using service ammunition. There was also a mismatch between ammunition capability and the optical devices used for acquisition and for measuring performance in training.

Army Fighting Vehicle Tactical Tables

Tactical tables were an innovation in mounted close combat training needed by a unit to operate on a 360° battlefield. The new tactical tables were not established or supported as mandatory; only earlier Gunnery Tables were trained consistently.

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2 MILES, COFT and SIMNET were used to support training for the U.S. team that won the Canadian Armor Trophy in 1987.

3 Training the crews of four battalions to achieve 100 percent certification on UCOFT (Unit Conduct of Fire Trainer) before live-fire gunnery improved the average score on Table VIII from 756 to 837 (11 percent) (Blackwell and Brown, 1994).

Reserve Component Training

Basic assumption is that training support developed for the Active forces transfers automatically to the Reserve component. Different training methods and doctrine are needed for the reserves where time for training, rather than personnel or funds, is the most critical resource.

Undetermined

Required effectiveness data not yet available; most are current development programs

Tactical Engagement Simulation (TES)

National Guard Virtual Training Program

Battle Command Staff Training (BCST)

73 Easting, used interactively for "what-if" exploration

Modular Semi-automated Forces (ModSAF)

Rapid Task Training--prior to deployment

Adaptation of Tactical Engagement Simulation training strategies for other nations and for less capable U.S. personnel

All successful simulations have high user acceptance. They also have the benefit of a training program that shows how use of the simulator meets an accepted requirement. This is in direct contrast to less successful simulations that do not integrate use of the simulator into the overall training program. Some less successful simulators had specific technical deficiencies, such as the inadequate terrain data base in TRAINFIRE (due to insufficient funding), or blooming effects of tank training ammunition on thermal sights; such cases suggest either unanticipated technical problems or insufficient test and evaluation during the developmental process. The technical deficiencies, such as they are, do not appear to be challenging or insurmountable. One suspects that the attractiveness of new technology and insufficient concern with how it should be used in the training program can account for most deficiencies in this sample of Army simulations.

Lt. General Frederic J. Brown, USA (Retired) (1993, p. 5-1) makes the point that:

> the combination of the training requirements mandated by both AirLand Battle and the constraints generated by the ever-present and growing restrictions on conducting field training (funds, terrain, ecology, soldier time, and ever-present safety) can be attained only by deliberate design or "structuring" of the training process to ensure that specific training events occur in the manner and sequence desired to achieve intended task training purposes. This structuring seems essential if current training practices are

to be retained. Perhaps more important, it provides a way to train for the future, to train Third Wave Landpower. . . . It became evident that current training doctrine does not establish a rationale or methodology for rigorous design of explicit task training to standard advantaging emerging Tactical Engagement Simulation (TES). Until training development—a statement of explicit training purposes and associated rules for use—is established, the promise of training support (TES) cannot be realized.

NAVY SIMULATIONS[4]

The following simulations were reported by the Navy.

Successful Simulations

SH-60B

Operational Flight Trainer (OFT)

P-3C

Operational Flight Trainer (OFT)

Weapon System Trainer (WST)

F/A-18 OFT, WTT

Tactical Air Combat Training System (TACTS)

Battle Force Tactical Training (BFTT)

Simulations with Problems

Enhanced Naval Warfare Gaming System (ENWGS)

Undetermined (under development)

Maritime Synthetic Theater of Warfare (MSTW)

Aviation flight and tactical simulators are reported to be particularly successful in terms of transfer of training with appreciable savings in overall cost, although documentation of these findings was not provided. Helicopter and maritime patrol aircraft simulators are considered by many operators to be better candidates than other aircraft for simulator hour substitution because they do not require high g loads that fighter pilots say is

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4 The following were particularly helpful in providing information about the Navy's efforts in simulation: David Glenn, NAWC/TSD; Andrew Appleget, NUWC; Rudy Croteau, NUWC; Jerry Lema, Naval War College; Peter Kincaid, Institute for Simulation and Training; CDR Michael Lilienthal, DMSO; Dianne Dry, IDA Simulation Center; CDR James Clagor, (N889-F2) Training Device/NTP Coordinator, Aviation Readiness; CAPT Tom Travis (N812D), Head, Modeling and Analysis; George Phillips (N812D2), Team Mike; CAPT Raymond Morris, PMA-205; Louis Solomon, ARPA.

important in a flight simulator. Additionally, for SONAR, RADAR, ECM[5] and MAD[6] operators and tactical coordinators, the working environment of the simulator is little different from that experienced in flight. The primary test of a successful simulator for training these crew members is the fidelity of the simulated target signals and equipment displays.

User acceptance of flight simulators is generally high. The Tactical Air Combat Training System (TACTS) ranges have been particularly successful in providing Air Combat Maneuvering (ACM) training and are an integral part of the Navy and Marine inter-deployment training programs. The Battle Force Tactical Training (BFTT) system, although still under development, incorporates components that have demonstrated successful transfer of training into a full DIS-capable training system for individual through Joint training exercises (again, without documentation).

The Enhanced Naval War Gaming System (ENWGS) is considered less than successful primarily in its role in supporting the Naval War College War Gaming Center. ENWGS is a command-level exercise trainer, dependent on computer-based combat models, i.e., a simulation rather than a simulator. Although it may be useful in some applications, it has not been adapted to the requirements for support of high-level training games.

Flight Simulators

Operational Flight Trainers (OFTs), Weapons System Trainers (WSTs), and Weapons Tactical Trainers (WTTs) as a class have been some of the most successful trainers in the Navy inventory. Helicopter trainers have been particularly successful because helicopters do not experience high g forces, and because many emergencies cannot be practiced safely in the aircraft. Even some basic maneuvers, such as landing on a small ship, require extremely precise control and are best introduced in a simulator. Simulators are also well suited for training non-pilot crew members of both helicopters and maritime patrol aircraft. The flight environment for these air-crew is little different from that experienced in the simulator. Except for differences in noise and vibration levels, which can be simulated for cosmetic reasons, stimuli external to the crew compartment are essentially absent.

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5 ECM: Electronic Countermeasures

6 MAD: Magnetic Anomaly Detector

The F/A-18 OFT and WTT are reasonably representative of the current technology of aviation simulators and are an integral part of the Fleet Replacement Pilot training program. The Category 1 (Fleet Replacement Squadron) training syllabus includes 40 trainer and 77 aircraft flights.[7] A 1991 Naval Training Systems Center (NTSC) report showed that the WTT was effective in training transfer for both air-to-air and air-to-ground maneuvers (Pfeiffer and Dwyer, 1991). The subjects of this study were Fleet Replacement Pilots and the results may not be extrapolated directly to fleet pilots who are more advanced. A 1992 IDA study showed that transfer of training from simulators to aircraft does occur for F/A-18 fleet pilots for the air-to-ground mission (Hammon and Horowitz, 1992). Even so, some fleet pilots stated that simulators are not useful for continuation training because simulator flights do not produce the requisite rush of adrenaline and the simulation of g forces is not realistic. This opinion obviously reduces user acceptance even though objective studies show that such simulators are effective training devices. A summary of the reasons for successful simulators in the Navy is given in Fig. IV-1.

The alternative to using simulators is to do all training in the aircraft. This is not only more expensive, but may be dangerous. For one maneuver, Pfeiffer and Dwyer, 1991, could not use an "aircraft only" control group because it was not considered safe to start Fleet Replacement Pilots out in a single place aircraft, and not enough two place aircraft were available. Additionally, many helicopter emergencies cannot be simulated in the aircraft for safety reasons.

Flight simulator technology basically uses off-the-shelf aircraft software and instrumentation. Simulator technology is well developed, but modifications to meet standard protocols for networking are needed to advance aircraft tactical simulation into the DIS mode and to attain needed portability.

Although acceptance of the OFT and WTT by Fleet Replacement Squadrons is quite high, usage data for fleet squadrons indicate that further substitution by fleet squadrons is possible. A sample of Marine squadrons used these trainers for an average of 0.3 hours/pilot/month in FY92. The average for all east coast Navy F/A-18 squadrons was 1.5 hours/pilot/month. Average flying hours/pilot/month were 21 and 18.5, respectively.

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7 VMFAT 101 Training Syllabus.

Reason for Success	Simulator
high user acceptance	all cases
acceptable fidelity	
target signals	P-3C, SH-60B
air combat maneuvering	TACTS, F/A-18 WTT
visual display	dome technology for F/A-18
g forces	bladder, g suit F/A-18 g forces not needed for P-3C, SH-60B because aircraft maneuver motion at low g forces
combat work environment	for new pilots in F/A-18
train emergency procedures	BFTT, P-3C, SH-60B, F/A-18
provides feedback for training	all cases
cost savings	BFTT saves OPTEMPO F/A-18 flying hours reduced 0.3–1.5 hrs per month
no acceptable alternative for training	TACTS

4-6

Figure IV-1. Reasons for Successful Simulations in the Navy

F/A-18 simulators show some shortfalls with regard to their ability to simulate the full mission environment and transportability to aircraft carriers. Positioning the aircraft for an air-to-ground weapon delivery is a demanding task, but the true measure of mission mastery is to be able to get to the target, deliver one's weapons effectively and egress safely in a hostile environment. Current simulators do not test the air-crew's ability in an environment that includes ground opposition and electronic warfare. In the past, these tasks could be practiced to some extent in the aircraft. However, as budgets decrease, we have an increased requirement for coordinated operations in a simulated hostile environment. Additionally, transportability is needed so that simulators can be used aboard aircraft carriers to review basic flight and emergency procedures, and for mission rehearsal.

WTTs are currently installed in suites of two and have a maximum interoperability of one-on-one or two aircraft against up to four simulated targets. This, along with the inability to introduce an electronic warfare environment or ground fire, limits the potential usefulness of the device, especially for fleet squadrons. Mission rehearsal capability is also

limited by the lack of recording and retrieval of performance data, and by the size of the simulator installation. Operating and Support costs per hour for the F/A-18 WTT are approximately $250, just over 10 percent of the cost of one hour of F/A-18 flying time.

The Air Force is examining the utility of distributed interactive simulation to provide air combat training by using the multi-ship air combat simulator facility for the F-15E at McDonnell Aircraft Company (Thomas and Houck, 1990). The Air Force and Navy are also examining simulator networks in conjunction with the Joint ACM Training System. The Naval Aviation Training Systems Advisory Group (NATSAG) has made this a Technology Requirement action item.[8] Currently the Navy has no technology requirement for developing a multiple aircraft, electronic warfare, ground threat environment for Weapons Tactical Trainers. This might be a potentially high pay-off technology area.

Portability might be attained through the development of virtual environment (VE) technology. A VE trainer, with a helmet a little heavier than a standard flight helmet, would fit in a cabinet which is approximately 10 × 6 × 3 feet. An F/A-18 trainer test bed which has received quite high marks from F/A-18 pilots is being developed at the Naval Air Warfare Training Center. At this point, its major deficiency is that the field of vision does not respond to head movements. However NAWC personnel are confident that this can be overcome. They cite work with a liquid crystal display (LCD) projection system development at MIT as a performance requirement and research by the entertainment industry as indicators that the program can be successful. The Institute for Simulation and Training at the University of Central Florida has developed a head mounted display which does keep track of head position and where the subject is looking.

Tactical Air Combat Training Systems (TACTS)

The Tactical Air Combat Training System (TACTS) ranges are used to train fleet pilots in intermediate and advanced air-to-air combat skills. The ground tracking system keeps track of all aircraft on the range and records simulated attacks and results. The total tactical picture is recorded for later debrief of the participants.

The only current alternative to training on the TACTS ranges is uninstrumented air-to-air exercises. Such engagements are practiced from day to day as part of the squadron training syllabus, but actual outcomes and information on the use of proper procedures are

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8 CNO (N889) ltr. ser. 889F4/3U658330 of 10 December 1993, Subj: NATSAG Conference 13–15 October 1993.

speculative. Readiness for flight on a TACTS range is provided by WTT and WST simulator flights. However, these simulators do not approach the TACTS ranges in realism of threat environment, numbers of units, or difficulty.

With the stand-down of two of the five active duty adversary squadrons, the Navy recognizes a need for alternative ways to exercise against dissimilar aircraft and air-crews outside the immediate squadrons. There is a further and more critical need to incorporate TACTS range fleet exercises with the full carrier battle group and with joint forces. Advanced exercises and research and development also require secure links to the aircraft to ensure that the data cannot be exploited for intelligence purposes, by either a real enemy or one in an exercise. A long recognized shortfall of the system is the inability to sort out targets or friendly aircraft that are within the same spatial cone but at different ranges.

Much of the potential improvement of TACTS requires no real stretch in technology. Rather, the requirement is for cooperation among Navy, Marine Corps, and Air Force. This cooperation has been initiated with agreement to the operational concepts required of the TACTS/ACMI system and JACTS (Joint ACTS). These programs would require further development of technology in order to upgrade the electronic warfare threat environment, encrypt the computer/aircraft links, and resolve the target resolution problem. These technologies are well within reach with the possible exception of target resolution which may be difficult to achieve. Problems with some simulators in the Navy are summarized in Fig. IV-2. Desired improvements in some Navy simulations are listed in Fig. IV-3.

lack of jamming	**TACTS**
lack of ground threats	**"**
need multiple friendly and enemy aircraft	**F/A-18**
lack of submarines, aircraft	**BFTT**
simulator expensive and not portable (for carrier use)	**all OFT, WST, WTT**
limited performance recording and retrieval for feedback	**"**
limited mission rehearsal capability	**"**
lack encrypted links to other platforms	**TACTS**

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Figure IV-2. Problems With Some Simulators In the Navy

Desired Improvement	Simulator
simulation of more combat units	BFTT
include aircraft simulators	BFTT
include USMC landing force	BFTT
central scenario generator	BFTT
lightweight headset and see-through projection surface	Virtual Environment Testbed at Naval Air Warfare Center Training Systems
replace high cost dome visual display	F/A-18, SH-60B OFT/WTT
semi-automated force	ENWGS
compatability with distributed interactive simulation	ENWGS
encrypted links to all platforms	TACTS

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Figure IV-3. Desired Improvements in Some Navy Simulations

The Navy is currently developing a technology requirement for incorporating TACTS into a fleet-wide system as part of the Tactical Combat Training System (TCTS). This will require a standardized DIS protocol, as well as an expanded geographical area of operations. Additionally, a requirement exists for a simulation environment generator that can communicate with other distributed systems.

Battle Force Tactical Training (BFTT)

Battle Force Tactical Training (BFTT) responds to the draw-down in the Naval force and OPTEMPO and is intended to provide individual through Joint training throughout the training cycle while ships remain in their home port. Ships are home ported by type at widely separated localities. During the initial and intermediate training phases, it is not practical to assemble all ships of a Carrier Battle Group in the same location. BFTT is also intended to take advantage of the assumed superior training environment of the trainees' own ship.

The BFTT concept has received high user acceptance by the surface community and will provide the on-board capability for the Tactical Combat Training System (TCTS). The essential elements are a central environment generator ashore, a communications link, and embedded on-board trainers (OBTs). This system has been demonstrated using equipment and technology being developed at the Navy Undersea Weapons Center at New London, Conn., and Newport, R.I. (Irvine and Quintana, 1994). These are the Tactical Advanced Simulated Warfare Integrated Trainer (TASWIT) as the central environment generator, the SSQ-89 sonar OBT, and a DIS-compatible Local Area Network (LAN).

An alternative to BFTT is to use on-shore trainers for initial individual, team, and unit trainers followed by operations at sea. This is the current system and it entails moving personnel to existing trainers and expensive at-sea operating periods. Individual, team, and unit training can be conducted throughout the interdeployment training cycle without the requirement for TEMADD funds or the loss of personnel for other shipboard requirements. An additional advantage is that BFTT will generate real time data that can be used for instantaneous play-back and debriefing.

The technology required to complete BFTT exists but further engineering development is needed. The BFTT program manager is currently pulling together existing systems, such as TASWIT—or an alternative—and existing OBTs. Many existing on-shore trainers use simulation rather than stimulation. Stimulation is a term used in the Navy when external signals are fed into actual operational equipment, such as radars or sonars, to simulate enemy or friendly platforms. Adding a stimulation capability for all equipment may require additional technology advances. Communications links compatible with DIS standard protocol are available and technology should present no problem. All of the candidates for the BFTT central environment generators are not DIS compatible but this is not necessarily a technology problem.

When fully operational, the goal of BFTT is to provide a system for team and unit training in all warfare areas, links to support multi-ship and multi-port in-port training, and the gateway for the fleet to the Tactical Combat Training System (TCTS). Both the shore- and ship-based equipment required for TCTS are to be developed as part of BFTT. For submarines, however, embedded training systems are in the very early stage of development and organic data collection systems do not yet exist. It is planned to initially move submarine personnel ashore with full ship-based systems to follow when OBTs and debriefing systems are fully developed. This is stated to be an engineering rather than a technology problem by personnel at Naval Undersea Warfare Center and the Naval Air

Warfare Center Training Systems Division who are responsible for integrating the submarine training system.

There is no stated requirement for incorporating networked aircraft simulators in BFTT. This seems to be a major shortfall in that controlling aircraft is a major part of carrier battle force operations. Additionally, no requirement exists for surface units to be able to interact with actual aircraft assigned to the same Carrier Battle Group (CBG). This will further limit coordinated training opportunities. Neither will BFTT be tied in with a land-based distributed simulation such as the Marine Air-Ground Tactical Force (MAGTF) Tactical Weapons System (MTWS).

Another potential shortfall arises from the fact that BFTT and TCTS are supposed to have compatible central scenario generators but not necessarily the same one. This could result in costly redundancy since the scenario generator will be an integral part of the TCTS which will eventually reside in one of the BFTT ports on each coast.

Technology issues include stimulation of all equipments, incorporation of networked aircraft simulators or actual aircraft into a hostile synthetic EW environment, incorporation of the total amphibious task force, and a fully DIS-capable scenario generator. Stimulation of all equipments will require more advanced technology as would networked aircraft or aircraft simulators. Actual aircraft interoperability would entail technology at least as advanced as that required for JACTS.

Incorporation of the amphibious landing force in BFTT would require a change in synthetic environment generation technology beyond that planned for the system. As planned, the system concentrates on the ocean and air environments. Extending this to a simulated land environment would be difficult to achieve. Even without dynamic modeling, which is probably well in the future, the selection of a central scenario generator for BFTT should reflect a future need for state-of-the-art terrain modeling. The Navy is in the process of selecting a standard scenario generator from among BFTT, TCTS, TASWIT, and ENWGS. Promising synthetic environment generation and C3I technology should be explored in conjunction with the selection of a central scenario generator for BFTT.

The Enhanced Naval Wargaming System (ENWGS) technology uses a central processor and scenario generator which supports training at TACTRALANT, TACTRAPAC, and the Naval War College. ENWGS is also one of the final four candidates for the Navy Exercise Scenario Generator. The remaining text will concentrate

on the role of ENWGS in support of the Naval War College War Gaming Center (NWC WGC). The NWC WGC is responsible for supporting (1) educational war games, (2) war game instruction and research, and (3) high-level strategic games for defense agencies including U.S. and foreign war colleges, Unified and Specified commands, and the Department of the Navy.

Whereas the emphasis of NWC WGC is on high-level strategic games, ENWGS is targeted at the tactical level. Of 55 games, conferences, and seminars conducted by the NWC WGC in 1992, only seven used ENWGS for scenario generation. According to NWC personnel, ENWGS is too detailed and not capable of operating at big enough time-steps for their purposes. ENWGS is not DIS capable although a program is under way to rehost ENWGS on an open system (JMCIS architecture).

The NWC is investigating the possibility of computerizing some high-level strategic games, but has concluded that ENWGS would not be compatible with their objectives. Besides the time-step problem, they believe that it is important for their customers to be in their own surroundings as much as possible. Seminar type games better meet their educational objectives. ENWGS is used for some war college student games at the tactical level.

Enhanced Naval Warfare Gaming System (ENWGS)

ENWGS technology is mature computer scenario generation and retrieval with man-in-the-loop technology. There appear to be no major development problems remaining except to adapt the system to DIS compatible open architecture. The potential use of ENWGS for strategic war games appears to be limited. This does not appear to be a technology issue as much as a budgetary one. The system appears to be performing adequately for tactical games at TACTRALANT and TACTRAPAC. With the current rehosting, ENWGS will be supportable and not proprietary to Honeywell as was the case until recently.

The level of detail and data base generation at all stations in ENWGS contributes to the time-step problem cited above. There are no plans to incorporate Semi-Automated Forces, which is a critical requirement of the NWC WGC. This is related to the level of detail and time-step problem. The system is not DIS compatible, but this is planned for the near future.

The underlying shortfall appears to be primarily related to a lack of user requirements definition when the system was initially installed. ENWGS was designed for

TACTRALANT and TACTRAPAC and the upgraded version was also responsive to these users. Personnel at NWC WGC stated that there was very little interaction between them and the program manager and the system just grew.

Department of the Navy and Joint Interoperability

The Navy would benefit if it had a wargaming system that could respond to all potential users. Characteristics which should be included are: (1) meets requirements for DIS and joint interoperability, (2) leverage off the MAGTF Maritime Warfare System (MTWS) and Warfighters Simulation (WARSIM) for the land system to attain Navy and Army compatibility, (3) leverage off the National Air and Space Model for air capability, and develop a new maritime simulator. This same approach could be taken by exploiting the technology proven by ARPA during the proof of concept Maritime Synthetic Theater of War/C3I demonstration conducted in September 1993. This demonstration modeled the sonar and mine warfare characteristics of a portion of the Sea of Japan. The system developed by ARPA is a central scenario generator that relies on advanced but nearly proven technology; it uses advanced computer technology and a physics approach to modeling.

A potential Department of the Navy application is the single Navy Scenario generator with a full DIS and joint interoperability capability. By including all Services a scenario generator would meet the maritime needs of the Services and of joint interoperability. An initial application would be the Battle Force Tactical Trainer; ARPA personnel believe this would be a low-risk approach.

The probability of success of this effort is estimated as high by the ARPA program office. They base their estimate on the success of the Maritime Synthetic Theater of War/-C3I demonstration and the fact that the system uses a physics approach to scenario generation. They state that the granularity of the synthetic virtual scenario is close to our knowledge of the physics of the ocean, land, and atmosphere. Work is currently progressing on modeling the atmosphere—including changes in weather phenomena—for RADAR applications. Because the system uses advanced computing, ARPA also believes that land surfaces can be modeled, perhaps as a dynamic model. The major shortcoming at this point is that the demonstration model does not include a sophisticated recording and debrief capability. This capability is expected to be a matter of programming.

Summary

Successful simulations in the Navy are those that have high user acceptance, acceptable levels of fidelity (generally because the simulator closely resembles the actual command and control workplace, such as in the P-3C, BFTT and TACTS), provide feedback needed for training, and provide some cost savings (BFTT). Simulators that have problems tend to have limited capability, e.g., incorporate insufficient numbers and different types of platforms; this deficiency was not apparent when the simulators were designed. The desired improvements seem, in all cases, to be needed to enlarge capability. Since current technology appears able to meet most of these expressed needs, the real issue is probably one of priority in allocating funds and not one of technical feasibility. We found no reports that a simulator had problems because it did not fit into a well-developed training program, as was observed for some Army simulations.

MARINE CORPS SIMULATIONS[9]

The Marine Corps training program depends heavily on the use of simulators. About 90 percent of the Marine Corps investment in simulators for training is allocated to flight training. Successful applications are reported in five functional areas; brief descriptions of the training systems follow.

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9 We acknowledge, with appreciation, assistance provided by the following individuals:

Marine Corps Modeling and Simulation Management Office (MCMSMO),
Marine Corps Combat Development Command (MCCDC): Lt Col John Boyd, USMC, Mr. Gary Brisbois, and Colonel John Kline, USMC.

Training and Education (T&E) Division, MCCDC: Major Doug Doerr, USMC, Major Ed Flores, USMC, Major Chad Kirkley, USMC, Colonel Mike Monigan, USMC, LtCol Robert Orazi, USMC, and Colonel Walter Wood, USMC.

MAGTF Staff Training Program (MSTP) Division, MCCDC: Major Floyd Johnson, USMC, Mr. Dick Morrell, LtCol Paul Roy, USMC, Mr. Jeff Tkacheff, and Captain David Wood, USMC.

Marine Corps Systems Command (MarCorSysCom): Colonel John Cummings, USMC, Colonel Ki Harvey, USMC, LtCol Mike Przepiora, USMC, and Major Frank Wysocki, USMC.

Naval Air Warfare Center, Training Systems Divison (NAWC/TSD): Dr. Charles Beagles, Mr. Rick Beger, Dr. Robert Hayes, Major Bruce Henry, USMC, Major Joe Santilli, USMC, MSgt Will Tucker, USMC, Colonel Robert Tyler, USMC, and Mr. Larry Willis.

Marine Corps Headquarters (HQMC): Mrs. Linda Goodwin.

Marksmanship and Target Engagement

Indoor Simulated Marksmanship Trainer (ISMT)

Extrapolation from an extensive operational test program indicates that ISMT is a cost-effective complement to live-fire training programs: Weapon-qualification rates improve (especially for women Marines); ammunition costs are reduced; less remedial training is needed for weapon qualification; and fewer recruits are separated for failure to qualify with the rifle.

Precision Gunnery Training System (PGTS)

TOW[10] gunners trained initially with PGTS-TOW in Southwest Asia during Desert Shield said it was "just like the real thing." In Desert Storm, TOW crews achieved high rates of hits and/or kills per missile fired; one crew destroyed 10 tanks or armored vehicles with 10 missiles. Similar success with PGTS-Dragon has also been evident in the large improvement in target tracking proficiency and first-round hits in live-fire exercises. The cost savings incidental to PGTS are dramatic: one TOW practice round costs $8.1 thousand while a PGTS for TOW costs $30.3 thousand; one Dragon practice round costs $3.8 thousand while a PGTS for Dragon costs $22.9 thousand. To sustain gunnery skills, 24 practice firings are required per month. The cost of practice rounds would be $194.4 thousand for each TOW gunner and $91.2 thousand for each Dragon gunner, compared to $30 thousand and $23 thousand, respectively, for the entire training systems.

Remoted Target System (RETS)

The Remoted Target System consists of stationary and moving targets that can be made to pop up as troops maneuver over a relatively large exercise area. RETS provides training in skills heretofore trainable only in actual combat or in infrequent force-on-force, free-play exercises.

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10 TOW: Tube launched, Optically Tracked, Wire-guided missile.

Battle Management

Combined Arms Staff Trainer (CAST)

CAST enables its users to expand their knowledge of supporting arms employment and to practice skills in the coordination of supporting arms. They are cost-effective alternatives to field exercises which, due to high cost, are held infrequently.

Tactical Warfare Simulation, Evaluation, and Analysis System (TWSEAS)

A heavy demand for TWSEAS exists at Marine schools and by combat staffs of the Fleet Marine Force. About 80 exercises—mostly battalion-level—are run annually on four operational systems. Including exercise preparation time and post-exercise review, each exercise takes one to two weeks. TWSEAS is a cost-effective alternative to field exercises, which, for high-level staffs, are rarely conducted because the costs are prohibitive; TWSEAS exercises provide more realism than command post exercises.

TWSEAS limitations: Despite strong user acceptance, the analog-based TWSEAS will soon be replaced by the digital-based Marine Air-Ground Task Force (MAGTF) Tactical Warfare Simulation (MTWS) that was developed to overcome several TWSEAS limitations, which include: (1) documentation is lacking, making it difficult to modify and maintain; (2) too few units can be played; (3) area coverage is too limited; (4) NBC warfare, night operations, and reduced visibility conditions cannot be played; and (5) inability to be electronically linked to other Services' models for joint exercises.

Ground Combat Vehicles

Marine Corps Tank Full-Crew Interactive Simulation Trainer (MCTFIST)

MCTFIST is a portable precision tank gunnery system that trains the tank commander, gunner, driver, and loader on a wide range of gunnery tasks while in a stationary, powerless tank. Scenery, targets, and visual effects are presented through video monitors appended to tank vision blocks; the simulator is attached to the actual vehicle.

Training effectiveness and cost avoidance associated with MCTFIST are illustrated by the training experience of 13 crews of a Marine Reserve tank unit prior to a live-fire exercise: (1) Two training days previously required for safety training were saved;

(2) 95 percent of the crews achieved first-round hits on stationary and moving targets compared to a 50 to 60 percent rate in pre-MCTFIST training; and (3) all training requirements were met with 300 fewer than expected (without MCTFIST) main gun rounds fired ($120,000 cost avoidance). MCTFIST was acclaimed by a Marine Reserve tank unit that received initial MCTFIST training aboard ship en route to Southwest Asia during Desert Shield. They attribute their combat readiness and subsequent success in a tank battle near Kuwait City to MCTFIST training prior to Desert Storm. The success of MCTFIST has led to the adoption of the appended-trainer concept—Combat Vehicle Appended Trainer (CVAT)—to training for all Marine ground combat vehicles.

Aircraft

Operational Flight Trainers (OFT), Weapon System Trainers (WST), and Weapons Tactics Trainers (WTT)

These flight simulators are fully integrated into flight training programs, which require a mix of simulator flying and actual flying. For the aircraft listed below, flight training programs in FY 1994 require the indicated number of flight simulator hours as a percentage of total syllabus flight hours (aircraft plus simulator) for the trainee to become combat capable.

Training programs for four Marine aircraft in 1994 require from 13 to 37 percent simulator hours as a percent of the total syllabus flight training hours (aircraft plus simulator) for the trainee to become combat capable (Figure IV-4). Helicopter flight is afforded fewer training hours, both in the simulator and in the aircraft, than fixed-wing flight; the latter are advanced aircraft.

Aircraft	Simulator Hours	Simulator Hours / Aircraft + Simulator Hours
AV - 8B	140.4	37 %
F/A - 18	95.0	28 %
CH - 46	69.0	34 %
CH - 53	20.0	13 %

Figure IV-4. Flight Simulator Hours as a Percent of Total Syllabus Hours (Aircraft Plus Simulator) for Trainee Aviator to Become Combat Capable

Simulator flights must be performed satisfactorily before follow-on aircraft flights can be scheduled. Because of their realism and their ability to host emergencies too risky to

simulate in aircraft, simulators may be used for: (1) up to 50 percent of minimum flying hour requirements; (2) flights to evaluate operational procedures; (3) instrument and NATOPS[11] check flights; and (4) 50 percent of minimum flying requirements for instrument rating.

The Marine Corps has 27 flight simulators that cost $394 million (then-year dollars). In the case of two aircraft, the investment in simulators is 2 to 5 percent of the investment in aircraft (Figure IV-5). Both aircraft and simulator hours in flight training programs have increased over the last ten years, with a larger increase for simulator hours (Figure IV-6). The proportion of simulator hours in this total has also increased, except for the CH-53E.

Number of Aircraft	Total Cost	Number of Simulators	Total Cost	Simulator $ / Aircraft $
283 AV-8	$6,606 million	6	$117 million	2 %
116 AH-1W	$1,104 million	3	$ 56 million	5 %

Figure IV-5. Relative Investments in Aircraft and Simulators, for the AV-8 and AH-1W aircraft

	Aircraft Hours				Simulator Hours				Simulator Hours / Aircraft Hours			
Aircraft	1983	1986	1991	1994	1983	1986	1991	1994	1983	1986	1991	1994
F/A-18			216.3	243.1			75.3	95.0			.35	.39
AV-8	164.8[a]		188.7	234.7[b]	12		74.5	140.4	.07		.39	.60
CH-46	153.5	121.0	129.5	131.5	30.0 (36.0)[c]	17.5 (22.5)	16.0 (20.5)	69.0 (7.5)	.43	.33	.28	.58
CH-53E	147.0	145.0	136.5	128.5	d	15.0 (7.5)	18.0 (11.0)	20.0 (0)		.16	.21	.16

a AV-8A.
b Radar-equipped AV-8B.
c Parentheses indicate simulator flight may be used if available.
d Simulator not available.

Figure IV-6. Flight Training Programs in the Marine Corps for Basic Pilots To Become Fully Combat Qualified

11 Naval Air Training and Operating Procedures Standardization.

Simulator flying is mandatory in fixed-wing training programs. In helicopter training programs, a large part of simulator flying has been optional, i.e., some training missions can be flown in simulators, if they are available, or in aircraft.

Two shortcomings have made the use of simulators less vital to helicopter flight training than to fixed-wing flight training:

1. Low-fidelity video poorly represents terrain, vegetation, and other external objects in the low-level flight regime, where helicopters operate most of the time.
2. Simulators poorly imitate the stability and control of helicopters; helicopters are easier to fly then their simulators.

Maintenance

Universal Maintenance Training Systems (UMTS)

UMTS is a networked panel trainer with software and video that allow an instructor to train students at 21 individual stations at one time. UMTS, which makes maximum use of commercial off-the-shelf hardware and software, provides training for operation and maintenance of complex equipment without the need for actual equipment. The generic nature of the system enables it to be adapted to new courses at a fraction of the cost of developing a new trainer. The interactive nature of UMTS provides an environment that helps turn out students with consistent knowledge and capabilities.

Findings: Marine Corps

Successes

Strong user acceptance; heavy usage.

Simulations are vital parts of ground and aviation training programs.

Portability is an important characteristic of some training devices, that can be used to exercise skills while deployed and/or embarked aboard ship.

Pervasive opinion of Marine Corps officers (Lt Colonels and Colonels) is that Marines trained with simulators today are much better trained than Marines who trained in the past without them.

Problems

Cost of converting present closed-loop simulations to DIS compatibility.

AIR FORCE SIMULATIONS[12]

A review of Air Force experience with simulation was facilitated by the fact that this subject was evaluated recently at the highest level and reported in "Four-Star Flight Simulator Review" (Department of the Air Force, 10 May 1993). This is, obviously, an authoritative document and much of the information that follows is derived from that report. The purpose of that review was:

> Examine Air Force flight simulator policies and programs to identify cost-effective approaches to flight simulation and obtain direction on future flight training simulator investment strategies.

Guidance on the use of simulators by the Air Force was provided by an earlier review (Department of the Air Force, 1984) and directive (1985), as follows:

Simulators complement flying time	Simulation Broad Area Review, 1984
Concentrate simulator training on tasks that cannot be trained effectively in the aircraft. Because of high cost, limit sophistication of flight simulators	"
Adapt commercial training where appropriate	"
Develop system training plans	"
Use contractor logistics support to free up maintenance personnel to support direct combat needs	Program Management Directive 5220, 1985
Phase out aircrew/missile training device career field	"

The Air Force is committed to a simulator development program that will cost about $2.2 billion, including RDT&E and procurement. About equal amounts (about $0.7 billion each) will be spent for training systems for air crew and weapon systems (Figure IV-7).

12 We acknowledge the assistance of the following individuals who were most helpful in obtaining information on simulation and training in the Air Force:
James D. Basinger, James J. O'Connell and James Brown, Air Force Training System Program Office; Patrick Bowden and Robert Denton, Air Force Education and Training Command; and Martha Weller, Institute of Aviation, University of Illinois.

Training Systems	RDT&E ($ Millions)	Procurement ($ Millions)
Air crew	$310.5	$409.0
Maintenance	290.6	329.9
Electronic Warfare	9.9	31.8
Weapon system	217.7	520.4
Development activities	94.9	
Total	$923.6	$1,291.1

Figure IV-7. Air Force Simulator Development Program (Source: *Four-Star Flight Simulator Review*, 1993)

Deficiencies of current and still-to-be delivered simulators, as reported by the major commands, are shown in Figure IV-8.

Command	Deficiency
Air Training Command	
Joint Primary Aircrew Training System/ Ground-Based Training System	None (system available FY 98)
Electronic Warfare T4/T5 PTT	No devices for training (1) suppression of enemy air defense (SEAD) principles (2) integrated electronic combat
Air Mobility Command	
Joint Primary Aircrew Training System/ Ground-Based Training System	Inadequate visual system Inadequate receiver/tanker interaction models
Electronic Warfare T4/T5 PTT	Insufficient WSTs to meet training demands
C-5 WST ARPTT	Inadequate visual system Poor receiver/tanker interaction model Insufficient WSTs to meet training demands
C-141 WST, ARPTT	Inadequate visual system Poor receiver/tanker interaction model Navigator unable to perform air drop duties in WST
C-130E/H WST	Aero model differs from a/c at low altitudes and on the ground
C-130H-2/WST	No WST configured for this a/c
C-130H-3	Available simulators inadequate for systems peculiar to this a/c
C-17	(Awaiting flight test aero data)

(continued)

Figure IV-8. Evaluation of Air Force Simulators

Command	Deficiency
Air Mobility Command (cont'd)	
KC-10	Computer cannot support further modifications to the system
KC-135	Inadequate visual system Excessive computational lags Performance differs from a/c No motion
Special Operations Command	
SOF Aviation Training System	Unanticipated cost growth Required funding unavailable Training materials not available
Combat Air Command	
F-22	None (awaiting delivery)
F-15/F-16	Primarily a procedures trainer Does not provide required training Expensive to operate and maintain
A/OA-10	Required simulators not available since retirement of low fidelity OFTs
F-15A/C	No visual cues
F-16A/B	Lacks visual cues for practicing out-of-control recoveries
F-15E	Lacks visual cues (full dome was canceled)
B-1	None identified
B-52 WST/OSMT	Cannot train conventional tactics and weapons delivery
B-2	None identified (awaiting delivery)
JSTARS	Training uses KC-13J JSTARS-modified WST does not exist

Figure IV-8. Evaluation of Air Force Simulators (cont'd)

As reported in the Four-Star review, two major commands take different positions on the use of flight simulators for air crew training:

Air Mobility Command

Use flight simulators for aircrew training.

Reduce expensive flying hours, by up to 50 percent.

Increase use of simulators as years of pilot experience increases.

Use simulators for maintenance training.

Upgrade training devices first that have largest return on investment (C-5, C-141).

Air Combat Command

Use aircrew training devices to complement rather than supplement flying hours.

Widely dispersed small units dictate low-cost, high-fidelity simulators for training pilots.

Replace flight simulators with low-cost unit training devices.

Use simulators to train maintenance and part-task trainers for electronic warfare, IR target recognition, digital landmass.

An emerging concept in the Air Force is that, where feasible, current generation flight trainers should be replaced with low-cost training devices. Because of their high cost, only an insufficient number of flight trainers can be procured and some pilots have to travel to other bases to use them. Given the advances in computers and the reduction in their cost, the Air Force plans to develop multi-task trainers with a single visual channel that can be used for various training purposes, e.g., emergency procedures, instrument flight, approach, air-to-air tactics, IR, and use of digital land mass data. It is estimated that unit-level training devices to support F-15 and F-16 aircraft cost about $0.7 to $1.25 million each. The Air Force plans to procure 97 such devices and place one or more at each flight base. A comparison of the cost of ownership of current operational flight trainers and the proposed unit training devices, as shown in Figure IV-9, suggests that, due to savings, the total cost of 97 devices ($67.9 to $121.3 million) could be amortized in 0.9 to 1.7 years.

The Four-Star Flight Simulator Review concludes that:

Most weapons systems do not have system training plans.

There are data base deficiencies in the aero model in 14 of 43 simulator models.

Standardized data bases are necessary for realistic training.

Simulator technology is available which can provide high-quality simulation at low unit cost.

Lack of currency between simulators and aircraft is a major concern of all MAJCOMS.

Operating Costs, per year

	Operational Flight Trainers	Unit Training Devices	Savings, per year
utilities, per facility	$ 300 K	$ 11 K	$ 289 K
contractor support, per device	500	40	460
total	$ 800 K	$ 51 K	$ 749 K

Estimated cost of unit-level training devices	$0.7 - $1.25 M per device
Cost of 97 devices	$67.9 - $121.3 M
Estimated savings	$749 K per device x 97 devices = $72.6 M per year
Amortization	Cost/savings per year = 0.9 - 1.7 years

4-19

Figure IV-9. Comparison of Cost of Ownership of Operational Flight Trainers and Unit Training Devices (Source: *Four-Star Flight Simulator Review*, 1993)

Summary: Air Force Simulations

1. The Air Mobility Command is willing to use flight simulators for aircrew training and replace training flying hours by up to 50 percent. It will upgrade training devices starting with those that project the largest return on investment.

2. The Air Combat Command uses flight simulators to complement rather than to supplement flying hours. It plans to replace, rather than upgrade, current flight simulators with 97 low cost unit training devices and locate them at flying bases.

3. Most deficiencies in existing simulators are the result of decisions not to upgrade existing equipment or not to provide certain capabilities, e.g., improved visuals, motion bases, more units, or more capability (e.g., IR, EW). Current technology could meet most of these deficiencies, if so desired. The issue is policy and budget rather than technology.

FINDINGS

Successes

High user acceptance

Training program well developed

Use of simulation integrated into training program

Acceptable fidelity (e.g., target signals, maneuverability, visual display, simulation of g forces) provides a good combat environment

Trains emergency procedures

Provides feedback for training

Provides cost savings

No acceptable alternative for training

Problems

Inadequate or no training program

Various simulators do not provide conditions needed for training, e.g.,

- jamming
- ground threats
- multiple aircraft targets
- submarines
- encrypted links to other platforms
- semi-automated forces
- integrated electronic combat
- air drop duties for navigator
- compatibility with DIS
- NBC warfare, night operations, reduced visibility, compatibility with DIS

Inadequate simulation

- visual system
- aerodynamic model
  - receiver/tanker interaction
  - low altitude effects

on-the-ground movements

performance recording and feedback

mission rehearsal capability

approaching targets only; need lateral moving targets

mismatch between ammo flash and electro-optical sight (no blooming)

documentation needed for maintenance and modification

area coverage

Too expensive to operate and maintain

Not portable (for carrier or deployed use)

Insufficient units to meet training demands

Excessive computational lags

Computer cannot support further modifications to system

Service Experience with Simulations

1. Most deficiencies in existing simulators are the result of decisions not to upgrade existing equipment or not to provide certain capabilities, e.g., improved visuals, motion bases, more units, more capability (e.g., IR, EW). Current technology could meet most of these deficiencies, if so desired. The issue is policy and budget rather than technology.

2. Successful simulators have adequate training plans, fidelity adequate to the training plan, provide feedback for training, provide training not possible any other way (e.g., emergency procedures), and save costs.

3. Simulators reported to have problems tend to lack a training plan, capabilities that appear desirable now but which were not provided originally (e.g., jamming, multiple vehicles, adequate documentation, adequate performance measurement, portability) and are expensive to operate and maintain.

4. The following trends are discernible:

Air Mobility Command	-	Use simulators to reduce flying hours up to 50 percent
Air Combat Command	-	Complement rather than supplement flying hours
		Replace flight simulators with many low-cost unit training devices

		Use part-task trainers for electronic warfare, IR target recognition, digital landmass
Marine Corps	-	Use simulators to reduce flying hours up to 50 percent
Army	-	Use simulators to reduce vehicle miles per year (SIMNET/CCTT)
All Services	-	Modifying existing simulations and simulators so that they can interact with other simulators and simulations of their own and other Services
		Developing distributed interactive simulation systems so that all types of simulations (simulators, live exercises and combat models) can participate in large-scale Service and joint exercises

5. If simulators are as effective as actual equipment for training personnel on certain specific tasks, as the data show, this could lead the Services to a reduction of OPTEMPO, i.e., because of cost savings, and an increased utilization of simulators. The Services differ in their response to this opportunity: The Air Mobility Command, Marine Corps, and the Army are increasing the use of simulators (flight and SIMNET/CCTT) and decreasing OPTEMPO (flying hours and vehicle miles); the Air Combat Command and the Navy use flight simulators to enhance but not reduce flying hours (except by a small amount). Little emphasis is given to the development of simulations for joint Service combat exercises, except for the ARPA and DMSO programs, such as, the Strategic Theater of War (STOW) and the Multi-Service Distributed Training Testbed (MDT2); the Services do participate in these development programs.

V. DISTRIBUTED INTERACTIVE SIMULATION

Distributed Interactive Simulation (DIS) is a current advance in technology that has great potential for improving training at unit, Service, and joint levels. It builds on the now familiar concept and technology demonstrated in the Simulator Networking (SIMNET) program that DARPA and the Army started in 1983. It depends heavily on standard protocols needed to support real-time communications between many participants (in the thousands) over intelligent networks; this type of capability is also called Advanced Distributed Simulation (ADS). Put simply, it creates an environment in which units of all sizes (e.g., Army and Marine battalions, brigades, or divisions, Air Force squadrons, and Naval task forces) separately or in combination, can engage in two-sided, real-time combat exercises, very much as if they were involved in a conventional large-scale field exercise on a well-instrumented range. The participants in DIS exercises, regardless of their actual locations, may be in simulators or in actual equipment, in simulated or in actual command and control centers, and, with some acting as an enemy, engage in a large-scale combat exercise on a common geographical location (which might be that of an assumed enemy). The environment is a synthetic one for personnel in simulators or for those in command posts who interact with computer-based combat models and a real environment for those in the field exercise who may not know that some participants are in simulators. All participants operate as if they were located in the same geographical area; those in the live exercise are actually there. This type of capability, although considered here only for purposes of training, has applications for mission rehearsal, test and evaluation of new equipment and weapons, and development and test of doctrine and tactics in a way that does not expose such activities to external observation.

The Defense Science Board Task Force on Simulation, Readiness and Prototyping strongly supported the development of distributed interactive simulation and recommended twelve demonstrations intended to improve training readiness, create a joint environment and provide support to acquisition (Defense Science Board, 1993). Six of the 12 demonstrations are directed to improve training readiness:

Joint Task Force campaign planning and training

Interactive exercises at home stations

Integrated National Guard Brigade training

CINC wargaming networking

Network training and test ranges

Realistic electronic combat test and training.

The viability and wide-scope capability of Distributed Interactive Simulation is attested to by the fact that at least 26 demonstrations, exercises, or tests of this technology have been held since 1987 or are planned for the near future; some have included forces in Europe and Korea (Figure V-1).

Current DIS development programs that relate specifically to training include the following:

	Estimated Program Budget[1]	
Close Combat Tactical Trainer (CCTT)	$ 2.1	billion
Aviation Combined Arms Tactical Trainer (AVCATT)	1.5	billion
Synthetic Theater of War (STOW)	350	million
National Guard Training	60	million
Multi-Service Distributed Training Testbed (MDT2)	11	million
Simulation Technology Development	98	million

The AVCATT is a prospective program. This list does not include many programs of the Services, DMSO, and ARPA that are developing the technology needed to support DIS (e.g., networks, virtual reality), but that are not specifically aimed at training. Some of these are considered below.

Training exercises conducted with DIS are likely to be cost-effective, compared to live field exercises, although we have not seen an analysis of this issue. According to Noble and Johnson (1991), the total life cycle cost of 546 CCTT simulators for company and team training is estimated to be $1.19 billion (FY 92 constant dollars). This cost can be "paid back" over 15 years by a reduction in OPTEMPO of 61 miles per tank per year (7.6 percent) from 800 miles for the Active Component and 45 miles per tank per year (15.6 percent) from 288 miles for the Reserve Component (Noble and Johnson, 1991). The total life cycle cost of 844 CCTT simulators for Battalion Task Force training for the Active Component and 114 simulators for the Reserve Component is estimated to be $2.1 billion (FY 92 constant dollars). The payback over 15 years would require a

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1 Source: Simulation Initiative Reply, DoD PA&E Memorandum, Dec. 21, 1993 and other sources.

reduction in OPTEMPO of 114 miles per tank per year (14.3 percent) for the Active Component and 45 miles per tank per year (15.6 percent) for the Reserve Component.

EXERCISE	AGENCY	DATE
CATC-87	DARPA/ARMY/ARI	Mar–Jun 87
FAADS/ADATS FDT&E	TEXCOM/USADAS&C	Mar–Apr 88 and Sep 89
USAFE JAAT	TAC/USAFE	Mar 89
WARE–03/90	ARPA/Army	Mar 90
BIT	ARPA/Navy	Jun 90
73 Easting	ARPA	91
13th I/ITSEC	Army	Nov 91
CTAS	Navy/UK	Nov 91
SASC Testimony	DDR&E	May 92
Ulchi Focus Lens	Joint–Korean	Aug 92
REFORGER '92	ARPA/Army	Sep–Oct 92
War Breaker Zealous Pursuit	ARPA	Oct–Dec 92
Louisiana Maneuvers IPR	Army	Oct 92
Maritime UAV	ARPA/JPO–UV	Sep–Dec 92
14th I/ITSEC	ADPA/Air Force	Nov 92
Missile Defense	DDR&E	Mar 93
Maritime Demo	ARPA	Sep 93
15th I/ITSEC	ARPA/Navy/OSTP	Nov 93
STOW Engr Demo	ARPA	Dec 93
INCOMSS-94	DDR&E/Army	Feb 94
SAFAGANZA	ARPA	Feb–Jul 94
MDT2	ARPA/STRICOM	Mar–May 94
AUSA	DMSO/Army	May 94
Capital Hill Support	DDR&E	Jun 94
STOW-E (REFORGER)	ARPA/Army	Oct–Nov 94
16th I/ITSEC	ADPA/Army	Nov 94

Figure V-1. Tests and Demonstrations of Distributed Interactive Simulation, 1987–1994

Regardless of the reliance placed on the use of CCTT, or more generally DIS, for training, it is useful to remember that some field training would still be needed, not only to build experience with and confidence in the use of the actual equipment to be used in combat but to provide training in tasks not intended for and not provided for in the design of the CCTT system. It is estimated that the CCTT can provide training for about 60 percent of the armor tasks specified in the Army Training Evaluation Program (Noble and Johnson, 1991).

CCTT is, of course, an improved version of SIMNET; several tests conducted in SIMNET suggest that CCTT will be an effective training device (See Figure V-2). When measured by the scores obtained on 55 tasks specified by ARTEP, platoons trained in SIMNET performed as well in three field exercises as those who received conventional field training (Gound and Schwab, 1988). A further analysis of the data in this report shows that SIMNET training on tasks that were judged fully trainable by SIMNET significantly improved the post-training performance. For a given subset of tasks that are fully represented in SIMNET, and within a given amount of time, SIMNET training is more effective than additional field exercises (Angier, Alluisi and Horowitz, 1992, p. 40 and Appendix B). Platoons with more battle runs on SIMNET produced higher scores in the competition for the Canadian Armor Trophy (Kraemer and Bessemer, 1987). SIMNET training on a field scenario improved field performance (TEXCOM, 1990); SIMNET training improved field performance ratings in the Armor Officer Basic Course over platoons that received conventional training (Bessemer, 1991). No known instance of training in SIMNET produced negative results.

Nevertheless, issue may be taken with these evaluations on the following grounds:

- Small sample size: Same performance of SIMNET and non-SIMNET trained groups, i.e., no significant difference between the groups, may be due to small sample size rather than to SIMNET training.
- No baseline: Control group (conventional training) needed as a baseline to estimate benefit of SIMNET training (except Ft. Hood test).
- Inadequate test design: Improved performance "due to SIMNET" may be due to additional field training (TEXCOM, Ft. Knox tests), increased experience of instructors, changes in rating scale, better student quality (Ft. Knox test).

Test	No. of Cases	Finding	Source
SIMNET training for Canadian Armor Trophy Competition	9 platoons	More SIMNET battle runs produced higher scores in CAT competition (r=0.53)	Kraemer and Bessemer, 1987
SIMNET training vs. conventional field training at Ft. Hood	8 platoons	No difference in scores on 55 tasks in 3 instrumented field exercises	Gound and Schwab, 1988
Additional analysis of above data: 10 tasks common to SIMNET and 8 STXs	8 platoons	SIMNET group performed better	Brown, Piskel, and Southard, 1988
Field exercise plus SIMNET training on same scenario: movement-to-contact	9 armor and 9 mechanized infantry platoons	All groups showed improved performance	TEXCOM, 1990
Performance ratings in Armor Officer Basic Course, Ft. Knox, 1987–1989	714 platoons, conventional training 39 platoons, SIMNET training	SIMNET Improved field performance ratings by 25 percent and saved 20 percent of time in course	Bessemer, 1991
SIMNET capability to train ARTEP MTP tasks (analysis, not test)	–	SIMNET can provide training on about 35% of ARTEP tasks	Burnside, 1990
CCTT capability to train ARTEP MTP tasks (analysis, not test)	–	CCTT can provide training on about 60% of ARTEP tasks	Noble and Johnson, 1991
British combat trials in AGPT	–	AGPT reduces navigation errors by 60 percent	Kelly, 1994
Operational tests of anti-helicopter smart mines vs. helicopters in SIMNET (not tests of training)	46 offensive and 40 defensive trials	Helicopter commanders improved their ability to avoid mines by 35 percent and mine layers improved deployment by 37 percent (exchange ratio improvements from first half to second half of trials)	Schwartz and DeRiggi ,1994

ARTEP Army Training Evaluation Program
MTP Mission Training Program
AGPT German SIMNET
STX Situational Training Exercise
CCTT Close Combat Tactical Trainer

Figure V-2. Summary of Studies Showing the Effectiveness of SIMNET for Training

Boldovici and Bessemer (1993, draft) provide an excellent discussion of the problems encountered in trying to evaluate SIMNET. Of great importance, obviously, is

how to evaluate the utility of CCTT for training and of other forthcoming DIS systems like STOW, MDT2 and the National Guard system. These DIS systems, almost by definition, operate with large numbers of people; the staff needed to develop and run a test and collect and evaluate the available data is not negligible in size. Ultimately, performance of the group trained in CCTT must also be measured in field trials, so that we can compare the field performance of troops trained conventionally with those trained using CCTT. We believe that insufficient attention has been given to develop test plans needed to evaluate the effectiveness and cost of DIS systems now being developed.

MULTI-SERVICE DISTRIBUTED TRAINING TESTBED (MDT2)

A significant program concerned directly with the utility of distributed interactive simulation for joint training is the Multi-Service Distributed Training Testbed (MDT2). The purpose of this program is to:

1. Develop a realistic synthetic environment primarily for training, but able to support mission rehearsal, execution, and feedback; the initial application is Close Air Support.
2. Develop and test training scenarios, assessment, and feedback for Close Air Support.

This is a multi-Service, collaborative effort with participation by all four Services:

Air Force Armstrong Laboratory, Mesa, AZ

Army Research Institute, Alexandria, VA

Naval Training Systems Center, Orlando, FL

Marine Corps Combat Development Command, Quantico, VA

SIMNET, Ft. Knox, KY

Tactical Operations Center, Mounted Warfare Testbed, Ft. Knox, KY

Naval Research and Development Activity, San Diego, CA

Patuxent Naval Air Test Center, MD

The budget for this program is a total of $10.5 million for FY 1993 and FY 1994 (Figure V-3). Each service contributes approximately equal amounts; about 40 percent is contributed by the Defense Modeling and Simulation Office (DMSO). When DMSO support ends after two years, it is anticipated that the Services will continue to support MDT2. Then, work on Close Air Support would be followed by training on such missions as Joint Air Defense, Combined Amphibious and Land Assault, and Joint Fire Support.

	FY 93		FY 94	
	SERVICES	DMSO	SERVICES	DMSO
ARMY	$ 1380 K	$ 1430 K	$ 1010 K	$ 425 K
NAVY	1100	620	810	300
AIR FORCE	1200	840	1000	410
TOTAL	$ 3680 K	$ 2890 K	$ 2820 K	$ 1135 K

Figure V-3. Budget for the Multi-Service Distributed Training Testbed (MDT2) for FY 1993 and FY 1994

The MDT2 program is correctly called a Testbed and it may in time develop into both a training and training evaluation program. Over the initial two years, about $6.5 million (60 percent) will go for the development and test of the hardware and software needed to operate the Testbed. About $4.0 million (40 percent) will be given to the development of scenarios and the conduct of tests of Close Air Support (CAS) needed to collect and evaluate preliminary cost and effectiveness data on the utility of this prototype for joint training. After the Testbed has been developed, it is estimated that 65 percent of all expenditures will be for tests of training with the residual (35 percent) needed to sustain operation and upgrade of the Testbed. Future programs supported by the Services are estimated to be of the order of $2 to $3 million per year. Due to limitations of time and funds, the program to test the capability of the Testbed for training the CAS mission will be based on performance measures within the Testbed before and after training during a period of five days; there will be about 30 people in 30–60 trials. This test design does not permit an estimate of how much training in the Testbed carries over to performance on an instrumented range or how well those trained in the simulator perform CAS on a range in comparison with those trained only on a range. Examination of training strategies, for the purpose of finding which methods of feedback of performance data best serve to improve performance, is also left for future work.

Some Service efforts that, though not performed as inter-Service projects, are focused on collective training and, by extension, can contribute to joint training, are considered here. The Air Force has linked two F-15C cockpits, an air weapons controller station, two enemy cockpits and two dome display systems in a distributed interactive simulation system, based on SIMNET-like communication technology (Bell and Crane, 1993). The system, called MultiRAD, for Multiship Research and Development, is located at the Aircrew Training Research Division of the Armstrong Laboratory, Mesa, Arizona;

MultiRAD also serves as the Air Force component of the Multiservice Distributed Training Testbed (MDT2). Four one-week exercises, with F-15 pilots and 13 air weapons controllers on 267 multiship missions, found the cockpits wholly acceptable for air combat training; the cockpits lacked rudder panels and had "glass" touch panels (computer-generated instrument displays). Tasks that were rated higher ("better") in MultiRAD training were employment of electronic countermeasures, employment of chaff and flares, defense against surface-to-air missiles, work with an air weapons controller, and engagement against four or more enemy aircraft. Tasks rated lower in MultiRAD than in current unit flight training were: tactical formation, visual lookout, mutual support, and visual low altitude flight. These are tasks that require visual imagery (beyond current simulator capability) and precise handling qualities of the aircraft. The lessons learned are based on pilots' comments and evaluations, not on performance measures in aircraft after MultiRAD training.

The Army Research Institute has developed a Unit Performance Assessment System (UPAS) that collects network data from SIMNET exercises and provides a variety of summary data for use in after-action reviews (Meliza, Bessemer, and Tan, 1994). These data include map displays with terrain features and contour, the overall battle space at any instant, line-of-sight display, true orientation of vehicles and gun tables, and pairing of firing events and artillery impact areas. This type of system has applicability for improving feedback and training in almost any type of distributed interactive simulation system.

Army battalions go to the National Training Center (NTC) every 18 months for field training exercises against the resident opposition force. The NTC is an instrumented range that provides both objective performance data and evaluations by Observers/Controllers to assess unit performance during exercises for use in after-action reviews. The Army Research Institute examined the training undertaken by seven brigades (2700 soldiers) in the six months before arriving at the NTC in order to identify key factors that led to success or failure in the exercises (Keesling, Ford et al., 1992). Strong, positive correlations were found for miles driven in training (a surrogate measure for the amount of training) and performance at the NTC; the correlation was 0.68 for force-on-force offensive missions and 0.80 for live fire defensive missions. There was a high correspondence between Observer/Controller subjective ratings and objective casualty exchange ratios. In general, brigades that performed better at the NTC managed their training better, concentrated their training on the more critical mission essential tasks (rather than on the entire list of tasks), more consistently followed the prescribed Principles of Training (Field

Manual 25-100), trained as combined arms and Service teams and used performance-oriented training for assessment and review.

FINDINGS

The current development of Distributed Interactive Simulation systems dedicated to training has estimated program budgets that total about $4 billion. This includes CCTT, AVCATT, STOW, MDT2 and National Guard Training. These funds are required to develop the hardware and software needed to provide large-scale combat environments before training can occur and to evaluate the effectiveness of training by these means, as well as for procurement, if these systems are shown to be cost-effective. Such evaluations will be novel, large-scale, complex, and labor-intensive efforts, both for the personnel needed to participate as subjects in these tests as well as for those needed to conduct the tests and evaluate the results. Apart from their size, the evaluations will be concerned specifically with determining the effectiveness of large forces in simulated combat, a difficult and not well developed art. It is important that planning and pre-testing of methods of evaluation and the development of alternative training strategies to be used to take advantage of distributed interactive simulation be undertaken promptly.

We were not able to review the joint training and exercise program. The Multi-Service Training Testbed (MDT2), supported by the Defense Simulation and Modeling Office and the Services, appears at present to be the only intensive program concerned with the effectiveness of methods of Joint training. The initial effort requires establishing the Testbed and no results related to methods of training are available at present. The STOW and National Guard programs can also contribute to Joint training. Some Service efforts related to large-scale collective training are undoubtedly relevant to Joint training but no efforts are known that may extend Service efforts to Joint training.

VI. TECHNOLOGY RELEVANT TO SIMULATION AND TRAINING[1]

In this chapter, we identify key issues in current technology that are critical to the development and effective use of simulation and training in the Department of Defense. Given the current emphasis placed on readiness and training by the Secretary of Defense and the Joint Staff, it is not surprising that major attention is being given to technology relevant to distributed interactive simulation, which is widely seen as an affordable way to supplement joint exercises and readiness. Thus, the following technologies are critical and significant to the effective performance of DIS:

Networks

Semi-Automated Forces (SAFOR)

Terrain and Environment

Range Instrumentation

Dismounted Combatants

Interfacing to Virtual Environments

Collective Training

This study did not investigate all technologies that may apply to Simulation and Training; rather, it looked at those technologies whose development is critical to its rapid progress. Recent briefing material[2] and available expertise provided the main guidance for selecting these particular technologies. Project reports and briefing materials that could be acquired were used, as appropriate.

Our review starts by identifying the areas of technology to be examined. For each such area, we discuss the most pertinent issues and present a table that shows examples of important ongoing projects. Projects are classified as major if they are funded at over $2 million a year, otherwise as minor efforts. The emphasis that a project places on each

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1 Assistance of the following individuals who provided information used in this chapter is gratefully acknowledged: Peter S. Brooks, Edward A. Feustel, J. Dexter Fletcher, Randy L. Garrett, and Anil N. Joglekar.

2 Advanced Distributed Simulation Update Briefing, Institute for Defense Analyses, January 1994.

issue in its field is rated as a major focus (dark shading) or a minor focus (light shading). Then, we summarize the status of work in each area and provide conclusions and recommendations. All dollar estimates are approximations.

NETWORKS

Today's network technologies cannot meet envisioned needs for real-time, distributed simulation. ARPA has provided the following comparison of current and envisioned network usage (Figure VI-1):

Today's Usage	Tomorrow's Usage
Small numbers of large-sized packets File transfer (latency tolerant) Computer-computer communication (Ethernet optimal~1400 Bytes) Performance severely penalized for other than standard Connectivity worldwide to reduce overall costs (connection-less vice point-to-point) Broadcast mode only	Very large numbers of small-sized packets Real-time simulation (DIS protocol ~250 Bytes) Video teleconferencing and voice traffic Connection-like sessions in connection-less environment Large bandwidth requirements with bandwidth reservation Widely distributed devices requiring larger WAN bandwidth Large numbers of members participating in many sessions

Figure VI-1. Comparison of Current and Future Usage of Networks (Source: Defense Simulation Internet Briefing, ARPA/ASTO, June 1993)

The underlying problem is one of scaleability; this is well recognized, as evidenced by the recent ARPA-sponsored scaleability peer review.[3] The issues that must be considered with respect to scaleability include the following.

Bandwidth. A major problem occurs when the number of simulation entities exceeds the capacity of (non-intelligent) local area network adapters. Unless backbone bandwidth can be delivered to every workstation, the amount of information that can be transmitted must be substantially limited. Additionally, there is a lack of validated methodologies for determining needed bandwidth for a given exercise.

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3 Cheriton, David R., Dale B. Henderson, Duncan C. Miller, David L. Mills, Stuart D. Cheshire, Randy L. Garrett, and Julia A. Loughran, Scalability Panel Review, IDA Document D-1451, October 1993 (draft).

Latency. Latency is determined by operating conditions in exercises and is constrained by physical laws, not subject to advances in technology. Current security mechanisms place an additional delay that results in a latency considerably greater than the maximum of 300 msec for application-to-application communication set by the Communication Architecture for Distributed Interactive Simulation (CADIS).

Security. This is a critical issue that significantly impacts all other technology issues. Current packet-oriented, E3, security mechanisms support less than 700 kbps. Mechanisms that exploit the potential of OC3 (~45 Mbps) are needed. Guidance in determining classification of exercises is also needed.

Interoperability. This chiefly addresses the integration of live, virtual, and constructive simulations, as well as linking simulations of the same type.

Multicasting. Multicasting is required to help reduce the volume of communications between geographically dispersed participants in simulated exercises; dynamic management of multicast group members, potentially participating in multiple exercises simultaneously, is also required. Currently, the dynamic memory of interface adapters and security devices each support only 1 to 16 groups, while over 4,000 are likely to be needed for a realistic synthetic battlefield.

Network and Exercise Management. The major problem in managing a network is dealing with the various local area network domains over a wide area network. Exercise management has to support the initialization, synchronization, checkpointing, and termination of exercise entities. There is a lack of experience in dealing with the orders of magnitude encountered here.

Focus of Network Efforts

Information on on-going efforts was obtained through review of relevant task descriptions and discussions with people associated with each effort. Several committees and infrastructure organizations are concerned with networks.

The Defense Modeling and Simulation Office (DMSO) has established a Networks Infrastructure Task Force to guide research and development in the network area. The charter of this group requires it to:

> Examine the network infrastructure required for Modeling and Simulation (M&S) and recommend to DMSO products, processes, and projects needed to address shortfalls.

Focus on wide area network services and capacity needed for growth and impact of transition to fee-for-service.

Develop a transition and integration model/roadmap for the distributed networking environment.

Identify the community served by the network.

Facilitate policy, standards, consensus building relating to networks, and synergy with the DIS protocol development.

ARPA and the Defense Information Systems Agency (DISA) have formed a Joint Program Office (JPO) for developing the Defense Simulation Internet (DSI) into a new network known as Defense Information Infrastructure Network (DIIN). This JPO will establish the set of services needed to support simulation in the 1995-1998 time frame.

Comments

A summary of current efforts is shown in Figure VI-2. Based on planned expenditures for known efforts, an estimated $100 million will be spent on network development; this figure is expected to increase substantially in forthcoming years. Due to the recent increase in available bandwidth, there has been much progress in this area during the last six months. This level of progress is likely to continue for several more months. Continued support of this critical area is vital.

	Focus of Technology					
Projects and Funds	Bandwidth	Latency	Security	Interop.	Multi-casting	Network Mgt.
MAJOR						
Defense Simulation Internet (ARPA)	////	\\\\	////		\\\\	\\\\
Advanced Technology Demonstration (ATDnet), ARPA	////		////		\\\\	\\\\
Defense Research and Engineering Network (DREN), ARPA	////				\\\\	\\\\
MINOR						
Improve Utilization of Wide Area Communications for DIS , STRICOM	////			////	////	
Dead Reckoning Project, NAWC		////		////		
DIS Protocols, STRICOM/IST				////	\\\\	\\\\

KEY

Funding	Focus of technology
Major: over $2 M per year	////
Minor: less than $2 M per year	\\\\
None: (blank)	

Figure VI-2. Selected Efforts on Networks

Several networks are being developed independently for a variety of applications, including high-performance computing, simulation, and video transmission. Efforts are needed to see whether, and how, these networks should be consolidated. As a minimum, steps should be taken to ensure that gateways are established between the major networks.

Asynchronous Transfer Mode (ATM) is a new low-level network protocol with both architectural and performance implications. Experiments that can determine its suitability for DIS are needed before a commitment is made to this approach. Although network management is being addressed quite widely, there are no efforts looking at the management of exercises, on top of network management systems. This issue needs to be addressed.

SEMI-AUTOMATED FORCES

Semi-Automated Forces (SAFOR) refer to entities on a battlefield (e.g., tanks, aircraft, trucks) that are controlled by computer-based algorithms rather than human operators. The "semi-automated" part of the title refers to the fact that SAFORs are monitored by a human controller who can modify their performance. SAFOR forces are needed to enlarge the number of participants on a battlefield without adding the cost of operating more manned simulators in large-scale exercises. SAFOR is a crucial underpinning of DIS. The heavy resource requirements and limited numbers of manned simulators will continue to necessitate the use of SAFOR. SAFOR is generally used to fulfill the role of threat forces.

Until recently, SAFOR systems had changed little since their inception in the SIMNET program. The first SAFOR system provided proof-of-principle demonstrations that established the feasibility and value of SAFOR for collective training applications. The development of second-generation systems has just begun. The new systems address broader communities, a wider scope of applications, and the need for increased validity in the behavior of SAFOR entities. Key issues in the use of SAFOR are the following.

Behavioral Realism. This addresses how SAFOR use the terrain, respond to environmental influences, and provide a credible, as well as realistic, representation of tactics and procedures that might be used by an opposing (or friendly) force. Improvement of behavioral realism is needed to extend the scope of operational training and increase the validity of SAFOR activities. The chief difficulty lies in developing improved models to represent more appropriate human behaviors than the current SAFOR can represent. To

enhance realism, SAFOR vehicles should also learn how to counter the tactics that live opponents (in this case, friendly forces) are using against it.

Higher Echelon Operations. Current SAFOR DIS models can operate weapon systems up to the level of company command. Higher level operations are needed to support a broader range of exercises. Demonstrations that include higher echelon command centers staffed with exercise participants are emerging, but semi-automated support is required to fully exploit this concept. One of the major difficulties lies in providing the necessary operational environments.

Command and Control Across Echelons. This issue addresses the need to (1) link the existing aggregate level command and control models into the DIS framework and (2) to link the command level staff with entity level representations. This new area is just starting to be investigated.

Computational Requirements. SAFOR was introduced as an economic means of filling out the synthetic battlefield. However, computational requirements increase as the complexity of SAFOR entities incorporate greater behavioral realism and can engage in a broader range of applications. This increases the cost of SAFOR forces and the economics of more advanced SAFOR entities.

Evaluation Methods and Standards for Behavior. There is a continuing need to compare the behavior of SAFOR in different applications of live and constructive simulations. Current efforts have focused on the evaluation of algorithmic components of simulations and have not addressed the comparison of battlefield operational behavior of simulations working together. Empirically based studies are needed to develop evaluation methods and standards for SAFOR behavior.

Focus of SAFOR Efforts

Information about on-going efforts shown in Figure VI-3 was obtained through review of relevant task descriptions[4,5,6] and discussions with people associated with each effort. A series of STRICOM/DMSO-sponsored reviews of the state and direction of

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4 Synthetic Forces Briefing, ARPA, ASTO Program Review, August 1993.

5 STRICOM Simulation and Training Technology Base, Significant Events Report, STRICOM, July–September 1993.

6 BBS and SIMNET Functional Prototype Project Update, September 1993.

SAFOR technology have been conducted. The findings from the most recent of these surveys[7] address the following points:

> Characteristics of existing SAFOR architectures that should be incorporated into future development efforts.
>
> Problems and issues that have not yet been addressed, for example, lack of a balanced representation of joint operations.
>
> Enabling technologies, for example, general computing technologies.

In general, the sponsorship for work to improve SAFOR should be broadened. A workshop could develop an organized approach to defining SAFOR requirements and monitoring advances in technology with respect to investments.

Effort	Behavior Realism	Higher Echelons	Command & Control	Computer Requirements	Evaluation Methods & Standards
MAJOR					
Modular Semi-Automated Forces (ModSAF), ARPA					
Intelligent Forces (IFOR), ARPA					
Close Combat Tactical Center (CCTT) SAF, STRICOM					
Institute for Simulation & Training (IST)SAF, STRICOM					
MINOR					
Battalion/Brigade Simulation-Distributed Interactive Simulation (BBS-DIS), ARPA					
IST SAF-Dismounted Infantry,STRICOM					
Mod SAF Verification, Validation &Accreditation, TRAC					
Eagle-Semi-Automated Forces–SIMNET, TRAC					

KEY

Funding	Focus of technology
Major: over $2 M per year	
Minor: less than $2 M per year	
None: (blank)	

Figure VI-3. Selected Efforts on Semi-Automated Forces

7 1993 DMSO Survey of Semi-Automated Forces, July 30, 1993.

Comments

Based on the current and projected funding for efforts in this area, an estimated $25 million will be spent this year. MODSAF (Modular SAFOR), and related ARPA programs, will be the main consumer of these resources. The resources invested in SAFOR development to date have resulted in useful progress being made. Considering the crucial role that SAFOR plays in DIS, continued investment is justifiable.

The programs being conducted in this area are not closely linked, and some relevant activities are being accomplished in different areas; e.g., this needs to be examined to ensure that related programs can appropriately leverage off each other. Therefore, one strategic recommendation is to build closer coordination between the organizations undertaking SAFOR programs. In addition, the needs of all potential user groups must be considered in order to ensure that the broadest possible use can be made of the developed SAFOR technology. In addition to training, the potential user community includes those with command and acquisition orientations. More effort is needed on evaluation methods and standards for the behaviors exhibited by SAFOR.

TERRAIN AND ENVIRONMENT

Modeling and simulation needed to support effective training is dependent on the location and environment of the scenario, and may need high fidelity physics and engineering models to provide a synthetic environment that includes time-and-space-varying information about the terrain, atmosphere, atmospheric backgrounds, oceans, and near-space with which vehicles, weapons, sensors, and communication must interact. The following factors dominate the technology needed to accurately represent the terrain and environment of an engagement.

Representation. The representation of terrain and environmental data should incorporate such features as visibility, electro-magnetic, and electro-optical propagation, voice communication, and vehicle movement. It should be physically scaleable to adjust to the constraints and capabilities of different simulations and simulators.

Rapid Generation. The generation of detailed terrain databases is currently a time-consuming process. Means of rapid database generation are needed to allow the timely support of unpredictable training requirements. Standards for protocols that permit the use of existing databases are also needed.

Dynamic Terrain. The current synthetic battlefield does not support modification of the environment in response to simulated events. For example, the effects of explosions on the land surface, and the effects of chemical weapons on atmospheric conditions, or actions taken by combat engineers to place bridges or create barriers, cannot be represented. The capability to support a changeable environment in real time is needed.

Computation and Connectivity. There is a need for real-time connectivity. Detailed representation of changing terrain and environment poses substantial computational demands; efficient support for Computer Image Generation (CIG) is also needed; networking of heterogeneous CIGs must also be addressed.

Standards. Standards are needed to simplify and facilitate the integration of information on the synthetic physical environment. These standards should address such items as database structures, transfer formats, and Protocol Data Units (PDUs). Their development must be coordinated with existing DIS-related efforts towards standardization.

DMSO has identified goals for representation of the physical environment. Although the technology issues represented are a composite of those previously discussed, Figure VI-4 provides a summary of the desired advances in the terrain and environment area.

Aspects of the Environment	Mid-Term Goals (1995–1999)	Long-Term Goals (2000–2008)
Data Bases	Network accessibility and portability of existing data bases across all environmental domains	High-speed, high-resolution coverage of the geospace with integrated and correlated treatment of the whole environment
Models	Adaptation and application of existing models to DIS	Synthesis of fast, full-spectrum, high-fidelity all weather models of the changing environment and its effects on systems performance
Visualization	Display of selected environmental components and features, with limited update capability and scaleability	Accurate, realistic and fully scaleable displays of the environment, with real-time interaction

Figure VI-4. Goals for Representation of the Physical Environment in Distributed Interactive Simulation

Focus of Terrain and Environment Efforts

Information on on-going efforts shown in Figure VI-5 was obtained through review of relevant task descriptions[8,9] and discussions with people associated with each effort.

Effort	Rapid Generation	Represent.	Dynamic Terrain	Computat. & Comm.	Standards
MAJOR					
Master Environmental Laboratory (NRL)		Major	Minor		Minor
Dynamic Environment/Terrain (USATEC)		Minor	Major	Minor	
Environmental Effects in DIS (ONR)	Minor	Major	Major		Minor
Special Operations Forces Aircrew Training System (ATS), AF				Major	
MINOR					
DIS Individual Warrior (DIS-IW), ARL		Minor	Major		
Environment Representation for Urban Terrain, STRICOM	Major	Major	Major		
DIS Working Group, DMSO					Major

KEY

Funding	Focus of technology
Major: over $2 M per year	Major
Minor: less than $2 M per year	Minor
None: (blank)	

Figure VI-5. Selected Efforts on Terrain and Environment

Comments

Based on planned expenditures for known efforts, an estimated $100 million will be spent this year. Similar amounts are expected to be spent in the next couple of years.

While issues with respect to representing terrain and environment in simulation are not new, work looking at these issues in the context of large-scale modeling and simulation for DIS has just begun. Accurate representation of terrain and environment is critical to the success of distributed interactive simulation for all purposes, and progress is expected to occur over the next few years. The rapid generation of terrain and environment is needed particularly to respond to terrorists and other no-warning hostile events that require an almost immediate military response. Authoritative representation of terrain and

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8 E2DIS Project Development Plan, prepared for DDR&E and DMSO, June 1993.

9 DMSO FY94 Focused Call and Team Assessment, Project 94-026.

environment is needed for planning at all levels, including joint operations. There is also a need to make certified and accredited representations available to the modeling and simulation community.

Major technical concerns relate to the management rather than to the development of new technology. In particular, there is a critical need for terrain and environment standards and supporting policy. The availability of appropriate standards will support and encourage developing the necessary compatibility between different terrain and environment databases.

RANGE INSTRUMENTATION

Most current field exercises are oriented towards a single Service and are often limited in scope because of cost and environmental factors. The current inability to include Division and Corp level echelons in DIS and the limited number of participants are just two examples of factors that impact the operational realism of these exercises. The ability to overcome these limitations by linking live simulations with virtual and constructive simulations is crucial to supporting today's vision of exercises and mission rehearsal. By supplementing field exercises with simulation-based unit training, both the span and joint character of training for combat could be significantly improved; in this way, data needed for Verification, Validation and Accreditation (VV&A) of models and simulations could also be developed. The need to facilitate this linkage underlies many of the issues discussed below.

Compatibility and Interoperability. Several concerns need to be addressed. One aspect is the compatibility between levels of detail in interactive live, virtual, and constructive simulations. Another is the difficulty of integrating activation of entities within a given visual range. The compatibility and interoperability of older systems is also a concern. Full interoperability requires that the issues of standards, latency, security, environmental compatibility, and time synchronization be resolved.

Adequate Terrain and Environment and Threat Fidelity. The linkage of live simulations with real and virtual simulations imposes more precise fidelity requirements. Digital terrains are a necessity, along with a useful representation of environmental conditions. The level of fidelity of computer-generated threats is also critical. Work is just beginning in this area.

Embedded Instrumentation. The instrumentation needed to record performance in field exercises is currently independent equipment added onto personnel and

platforms. The penalties of weight, power, and cost could be mitigated by integrating instrumentation systems with existing navigation and communications systems on various platforms.

Multi-Level Security (Encryption). The Air Force and Navy require that data transmitted on ranges be encrypted to allow the inclusion of advanced equipment in live exercises, whereas Army instrumentation cannot be classified. Hence, interoperability between these Services on ranges requires multi-level security. With the advent of the B-2 and F-22 aircraft in the next few years, there is an urgent need for this capability. Range instrumentation systems add difficult security requirements to DSI pertaining to size, weight, air-worthiness, and remote over-the-air rekeying and zeroizing.

C3I Representation and Support. There is a need to define the C3I information that should be captured to support concurrent virtual and live exercises. This information would provide a mechanism for integrating different ranges, in addition to integrating the different types of simulation. One of the questions to be addressed is whether C3I information should be recorded outside the range instrumentation system or DIS, or as another type of DIS entity. Fidelity, latency, and bandwidth are also concerns.

Standards. Standards in data types, data formats, data update rates, operational frequency, and network protocols are critical to the linkage of live simulations with virtual and constructive simulations across the DIS network. The DIS standard addresses only some of these concerns; challenges in the area of data rate and bandwidth need to be addressed. The majority of range instrumentation systems rely on radio communication networks. The bandwidth of these networks is limited to 200–800 kbps, as opposed to DIS data rates of 1.56 Mbps or higher.

Focus of Selected Range Instrumentation Efforts

Information on on-going efforts was obtained through review of relevant task descriptions[10,11] and discussions with people associated with each effort; these are summarized in Figure VI-6.

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10 Acquisition Plan for JACTS, No. AP53-001, Aeronautic Systems Center, Eglin AFB, Florida, June 1993.

11 JADS in Progress Review by Technical Advisory Board, Kirtland AFB, New Mexico, March 1994.

Comments

Based on current and projected funding for efforts in this area, an estimated $50 million will be spent this year. Of this, research, development, test and evaluation on the Joint Air Combat Training System (JACTS) and Tactical Combat Training System (TCTS) will consume roughly $17 million.

The community is sensitive to range instrumentation needs and many discussions have been held. Interoperability must be built into new systems and the start of positive actions can be seen in a decision to halt development of the JACTS and TCTS systems until interoperability issues have been addressed. When it is too late to fully address interoperability in emerging systems (e.g., MAIS), hooks must be included to facilitate the phased introduction of interoperability over time. Meanwhile, there are many incompatible existing range instrumentation systems, representing a national investment of some $2 trillion. A roadmap is needed to identify and guide the work needed to result in a set of fully interoperable range instrumentation systems.

Effort	Compat. & Interop.	Fidelity	Embedded Instrum.	Security	C3 Repres. & Support	Standards
MAJOR						
Joint Air Combat Training System (TACTS), AF/Tactical Combat Training System (TCTS), Navy		Major		Major		
Joint Advanced Distributed Simulation, OSD DT&E	Major	Major			Major	Major
Littoral Warfare, Navy	Major	Major				
MINOR						
Southwest Range Instrumentation, OSD DT&E	Major		Major	Major	Major	
High Dynamics (HYDY), ARPA	Major		Major			Minor
DIS Standards for Range Instrumentation, DMSO, IST						Major

KEY

Funding	Focus of technology
Major: over $2 M per year	(hatched)
Minor: less than $2 M per year	(hatched)
None: (blank)	

Figure VI-6. Selected Efforts on Range Instrumentation

It will take many years to reach the goal of fully interoperable range instrumentation systems. However, with the exception of network bandwidth, range instrumentation issues are not impacted by difficult technical challenges. Additional resources can speed up progress. The development of needed standards is particularly critical.

DISMOUNTED COMBATANTS

The role and importance of dismounted combatants, also referred to as individual combatants, on the battlefield has changed radically in recent years. This has led to a requirement for higher mission assurance and lower vulnerability for the individual combatant. The ability to allow dismounted combatants to interact with mounted forces in a synthetic environment provides a valuable training opportunity that responds to this requirement. The crucial test of technology developments will be the extent to which their inclusion of dismounted combatants enhances the utility of DIS for training field officers, as well as for mission rehearsal, logistics functions, and virtual prototyping and testing of new equipment.

As with the other areas of technology considered here, the technology required to support individual combatants is not unique to this area. For example, resolving the technology issues associated with individual combatants in DIS will resolve many of the problems with instrumenting individuals in live exercises.

Broadband Wireless Communications. A current issue is the introduction of voice communications into DIS. Voice communication PDUs are expected to outnumber entity representation PDUs by a ratio of 3:1. Possible resolutions to the increased throughput demands due to adding voice must consider some new factors, such as the effects of latency on human perception.

Environment Construction. Current simulations are based on Digital Terrain and Elevation Data (DTED) Level 1, a level of detail acceptable for interaction with simulated vehicles but not for individual combatants. The level of detail needed for individual combatants has not been specified and must be determined. Furthermore, individual combatants require the addition of vertical relief to support the representation of cover and concealment.

Human Perception. Immersion of individuals in a synthetic environment introduces many new concerns, such as high-resolution physical detail and behavior and cognition databases. (Interface and sensory interaction issues are discussed below in the section on Interfacing with Synthetic Environments.)

Behavioral Representation. Simulation of individual combatants will require icons of human figures which realistically portray a person's body and behaviors for friendly, enemy, and neutral soldiers, as well as the observer. Actual soldiers must be able to interface with these icons through the use of sensor devices that provide real-time control

of the model and data collection on their interactions. Various issues that need to be addressed include human response time, resource limits, collision avoidance, multi-person cooperative tasks, and handling three-dimensional acoustic data, as observed in the display.

Including Combatants in DIS. Existing DIS draft standards have not addressed special concerns relating to individual combatants operating in synthetic environments. Such concerns include greater fidelity in terrain representation in which humans can perform credibly.

Computational Requirements. Support for individual combatants will impose additional computational requirements. This is due to the impact of an increased bandwidth, and the need for more detailed terrain data and consequent trade-off of detail for an area of concern while preserving vertical and horizontal control.

Focus of Selected Individual Combatant Efforts

Information on ongoing efforts was obtained through review of relevant task descriptions[12,13,14,15,16] and discussions with people associated with each effort; these are summarized in Figure VI-7.

Comments

Simulation technology needed to portray dismounted combatants on the battlefield is a new area of research and development. The need for work in this area was highlighted in General Gorman's paper on SuperTroop (Gorman, 1990), and is evident through the use of individual combatant technology in the 21st Century Land Warrior Top Level Demonstration. Based on planned expenditures for known efforts, less than $10 million will be spent on this topic this year.

Recommendations for work in this area reflect the need to establish an infrastructure to organize and guide on-going work. An up-front analysis is needed to determine how individual combatant technology should be used to exploit the fullest potential from on-going and future work in this area. The primary question to be answered is: At what level

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12 DMSO FY94 Focused Call and Team Assessment, Project 94-010.

13 DMSO FY94 Focused Call and Team Assessment, Project 94-071.

14 Project Execution Plan for Environmental Representation of Urban Terrain, DMSO Project 94072 (undated).

15 The Integrated Unit Simulation System Briefing, US Army Natick RD&E Center (undated).

16 Simulation of the Individual Combatant Briefing, Cardinal Point, Inc., November 1993.

and with what amount of detail should individuals be introduced in various types of simulations and missions?

Effort	Comms.	Envir. Constr.	Human Perception	Behavior Rep.	Inclusion in DIS	Comp. Rqmts.
MINOR						
Integrated Unit Simulation System (IUSS)						
Combat Behavioral Representations for Military Operations in Urban Terrain (MOUT), USMC						
Multi-Service Dismounted Combatant Simulation (MDSC), ARL, USMC						
INFOSCOPE, ARPA						
DIS Individual Warrior, ARL						
Virtual Synthetic Environment for the Soldier System , ARL						

KEY

Funding	Focus of technology
Major: over $2 M per year	
Minor: less than $2 M per year	
None: (blank)	

Figure VI-7. Selected Efforts on Dismounted Combatants in Simulations

Individual combatant simulation technology has considerable dual-use potential. Technology that supports training the individual warrior has potential application for the training of many types of specialized operations, including fire fighting, special operations, and police work. Liaison needed to exploit this dual-use potential should be promoted.

INTERFACING WITH VIRTUAL ENVIRONMENTS

With the exception of limited numbers of manned simulators, the traditional interface to training simulations has been through the computer screen. Virtual reality technology attempts to provide a higher bandwidth communication channel between simulations and humans by immersing humans in a synthetic environment. Though the practical capabilities of this advanced interface technology are still uncertain, many believe that it offers a significant potential for military training. The issues identified below reflect critical concerns for both screen-based and immersion-based interfaces; they apply to interfaces for both operators of and participants in simulations.

Computer Image Generation (CIG). The degree of realism achievable in computer generated images is determined chiefly by interrelated factors such as polygon and pixel processing rates, the number of moving models, and the frame update rate. Many groups are already looking at how to provide increased capacity for CIGs at

affordable costs. Further examination of perceptual issues is needed to determine what physical capacity is needed.

Displays. Problems with monitors, flat panel displays, and Liquid Crystal Displays (LCDs) are largely those of manufacturing and affordability, and these are being addressed by industry. Helmet mounted displays (HMDs) and wrap-around projection screens are examples of technologies that warrant investigation for their role in DIS. Since each type of display has some advantages, it is likely that future simulation-based exercises will require the use of multiple types of displays.

Multi-Sensory Input/Output. The usefulness and fidelity of the immersion experience depends on the sensory environment provided by the interface. Progress has been made for visual and auditory interfaces; progress in other modes of interaction remains minimal. Advances are needed in, for example, unobtrusive support for locomotion, tactile and force-feedback interactions, tracking and navigation. The research must address the physiological, psychological, and perceptual issues related to such multi-modal interfaces.

Visualization. How complex data should be presented to a user is another important issue that needs clarification and further investigation. For example, visualization and spatial interpretation of massive databases, such as large air-ground areas, the human body, and ocean-land interfaces should be supported.

Adaptable, Intelligent User Interfaces. Interfaces need to be adaptive to the capabilities and needs of the different users. Moreover, factors such as the wealth of information that simulations are envisioned to make available and the increasing need for faster decision response times are increasing the burden on simulation operators and users. Intelligent interface agents that can mitigate this burden and provide some form of intelligent training will be needed.

User Interface Design Methods. User interface concerns can no longer be considered in isolation from other design issues. The needs and behaviors of operators, participants, and users of collected data must be modeled and actively included in the earliest design activities. While these concerns are important for training systems generally, their importance becomes crucial when interfacing with synthetic environments.

Focus of Efforts on Interfacing to Virtual Environments

Information on on-going efforts was obtained through review of relevant task descriptions and discussions with people associated with each effort. Current efforts are summarized in Figure VI-8.

Effort	CIG	Displays	Multi-Sensory I/O	Visualiza-tion	Adaptive, Intelligent Interfaces	Interface Design Methods
MAJOR						
Crew System Virtual Interface Technology, Armstrong Lab		///	///	///		
MINOR						
Tactile/Force Feedback for Virtual Environments in Training			///			
Virtual Medical Design Environment		\\\	///	///		
Virtual Physics Laboratory, NASA	\\\	///	///			
3D Audio for Virtual Reality, NRAD			///			
Virtual Environments Training Technology, NTSC	\\\	\\\	///	\\\	\\\	
Computer-Aided Systems Human Engineering, Armstrong Lab				///		///
Virtual Reality and Synthetic Environments, DMSO	///	///	///			

KEY

Funding	Focus of technology
Major: over $2 M per year	///
Minor: less than $2 M per year	\\\
None: (blank)	

Figure VI-8. Selected Efforts on Interfacing with Virtual Environments

Comments

Given the diverse nature of on-going work, and the multitude of players, it was not possible to estimate the level of effort being invested in interfacing to virtual environments. Progress varies by area. While advances have been made in display resolution, work on touch and feel (haptic) interaction has been less successful. The technology as a whole is advancing, but little is known about the worth of haptic interfaces on training and military performance.

The virtual reality (VR) aspects of this technology have been widely publicized in recent years. There have been numerous Service sponsored, and other Government agency sponsored, working groups looking at VR-related issues. Interest in the technology is not limited to the United States; for example, the Tri-Service VR Working Group for Training

Applications (UTP-2 Military Training Panel of The Technology Cooperation Program) has been fostering collaboration on this topic among the five English-speaking countries. In 1992, the Federal Coordination Committee for Science, Engineering and Technology (FCCSET) established a Task Group under the Subcommittee on High Performance Computing and Communications and Information Technology (HPCCIT) to assess Government interests and activities with this technology.[17] The National Academy of Sciences proposed an effort to develop a national agenda for VR research.

The diverse Government groups active in this area are largely working independently. There is a serious possibility that several independent development programs are not coordinated. In order to avoid unnecessary duplication of work, and the development of incompatible systems, the DoD must determine how to coordinate virtual environments interface work within the DoD as a whole and, preferably, within the entire Government.

In functional terms, the technology associated with virtual reality is treated here as a segment of Modeling and Simulation. Despite the large number of on-going efforts looking at many possible applications, there has been little work looking at the specific application of virtual environments interface technology to military modeling and simulation. The DoD needs to determine its near-term and long-term needs in order to focus on-going and future work that it supports. Except for Computer Image Generation (CIG) and displays, work in this area is in its infancy and needs careful consideration and guidance. CIG issues are being effectively addressed by industry. Specific technical recommendations for helmet mounted displays (HMDs) include the following:

Provide engineering specification for devices to allow definition of the spectrum of fidelity.

Develop test equipment to facilitate quality assurance of devices.

Assess impact of VR sickness on training effectiveness and operational performance.

Develop rules that promote easy adaptation and re-adaptation to VR devices.

Similar concerns will arise for other new input/output devices as their development progresses. In general, more attention should be paid to integrating human factors

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17 Virtual Reality Technology: A Report of the Task Group on Virtual Reality to the High Performance Computing and Communications and Information Technology (HPCCIT) Subcommittee, The FCCSET Committee on Physical Mathematical and Engineering Sciences, August 1993.

engineering considerations into on-going efforts. Further examination of perceptual issues is needed to determine required CIG capacity.

COLLECTIVE TRAINING

Live, virtual, and constructive simulations are major tools used for military training and their utility for developing and assessing joint readiness is likely to increase. While the availability of such tools is, of course, crucial, so is an understanding of what to teach, how to teach it, when to teach it, and whether that teaching was effective. Pertinent issues of technology needed to support collective training are discussed next.

Performance Measurement. The contribution that training makes to military readiness cannot be assessed accurately in the absence of performance measurement methods. There are many methods for measuring the performance of individuals, but there are few methods for assessing the performance of units or collective groups. The absence of agreed definitions of training objectives and of valid measures makes this a difficult but no less crucial deficiency to address. The incorporation of performance measures at every level of simulation will be the key to getting accurate measures of readiness at all levels, i.e., individual, unit, and joint readiness.

Instructional Strategy. This is a need for determining, for example, whether apprenticeship or Socratic training methods are more suitable for training on particular unit tasks. There are approaches for choosing between different instructional strategies for training individuals, but there is a lack of validated methods for unit training. In particular, there is a lack of understanding on how best to use combinations of live, virtual, and constructive simulations in a complementary manner for training.

Defining Critical Scenarios. The Services and the Joint Staff have developed lists of essential military tasks.[18] Methods for generating scenarios for critical essential tasks are needed to ensure the relevance of simulation exercises to training and military requirements at the highest levels.

Cost-Effective Training Mix. There has been some interest in defining the appropriate mix of, for example, simulation and live training, at the individual level but little at the unit level. Determining unit-level cost-effectiveness is particularly difficult since the set of missions that must be supported varies widely, e.g., from major regional

[18] Universal Joint Task List, MCM-147-93, The Joint Staff, 25 October 1993.

contingencies to operations other than war; unit training cost data are not easily identifiable in Operation and Maintenance accounts.

Skill Decay and Maintenance. Once again, more is known about skill decay and maintenance for individuals than for units. Here, the ability to measure performance is a prerequisite to development of training strategies for crews and units.

Focus of Training Efforts

Information on on-going efforts was obtained through a review of relevant task descriptions[19,20,21] and discussions with people associated with each effort; this work is summarized in Figure VI-9.

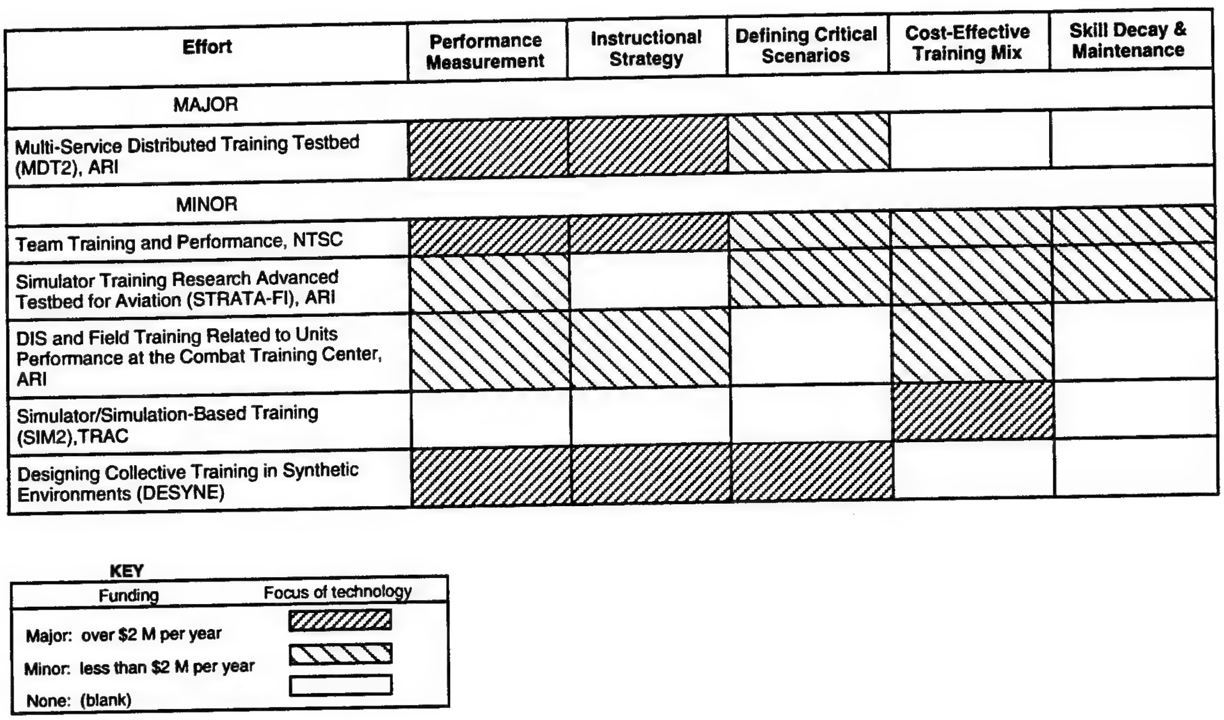

Figure VI-9. Selected Efforts on Collective Training

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19 DMSO FY93 FCP Program Status Summary Reports, 1993, Project 93-025.

20 MDT2 Project Development Plan, DMSO (undated).

21 Series of NTSC Technical Reports.

Comments

Based on current funding for the cited efforts, an estimated $15 million will be spent this year in this area as a whole. The Multi-Service Distributed Training Testbed (MDT2) effort will consume nearly half these resources.

The technology needed to support collective training, i.e., SIMNET and its derivatives, has been well established. But there is a recognized and critical need for training strategies that can take advantage of large-scale, distributed interactive simulation technology. Some enabling technologies, such as cognitive modeling, still have limited capabilities. What is lacking is the ability to apply these understandings to such issues as performance measurement and instructional strategy for training collectives, up to the level of joint operations.

There has been insufficient attention to this area. Without any real rapid progress, the lack of adequate training technology may severely limit the utility and use of DIS for training. It is uncertain whether spending more money can accelerate resolution of the identified technologies. A defined set of unit training objectives must be established and agreed upon. Demonstrations may provide a useful mechanism for forcing consideration of the pertinent issues and helping to identify these objectives. The basis for this exists in the Universal Joint Task List and the Joint Military Essential Task Lists of the CINCs. These task lists, with their conditions and standards, should be used to drive R&D and the application of training technology.

The issues discussed here are, in general, subordinate to the issue of instructional strategy for large combat units and this is the most important issue. In addition, performance measurement is needed to support R&D for all the other discussed issues.

FINDINGS

A review of technologies critical to simulation and training examined R&D on distributed interactive simulation in areas concerned with networks, semi-automated forces, terrain and environment, range instrumentation, individual combatants, virtual environments, and training technology. Areas that receive major funding ($100 million a year or more) are networks, terrain, and environment and range instrumentation. Within these areas, increased attention should be given to develop the Asynchronous Transfer Mode (ATM) protocol for DIS, support for exercise management, compatibility between terrain and environment databases, radio-frequency network bandwidths for range instrumentation, and communication standards. Less support is being given to methods of

training, design and use of individual combatants in DIS and SAFOR. There is a need for development of methods of evaluating performance in all areas, clarification of appropriate applications of individual combatants (including dual-use potential) in DIS, and effective ways to use and measure the training effectiveness of DIS systems.

VII. DISCUSSION

The current draw-down of about 30 percent in force structure and manpower leads to serious problems concerning the ability of the armed forces to accomplish their assigned missions. At the same time, missions have changed significantly from those associated with a nuclear-dominated, bi-polar world to those associated with a multi-polar world, major regional conflicts, small contingencies, and operations other than war. Senior advisory groups that have recently reviewed the current missions of the Department of Defense find that training is a major component of joint readiness and that distributed interactive simulation provides an important way to provide the training needed to maintain readiness (Defense Science Board, 1993; DSB Task Force on Readiness, 1994; Training Readiness in the DoD, 1994: Burba, et al., 1994). With this background, we wish to discuss lessons learned about simulation and training derived from information presented in this report. Where problems are identified, the purpose is to be constructive rather than critical.

Simulation is demonstrably a cost-effective method of military training. When it is evaluated, it is generally found to be as effective in training specific skills as the use of actual equipment would be; it saves student time and costs less to acquire and use than actual equipment. Savings due to the use of simulators for training can amortize their cost in periods of one to four years. This is a conservative estimate that does not include the costs of wear and damage to actual equipment used for training or of acquiring additional operational equipment needed to satisfy training requirements. Very preliminary findings, based on tests with SIMNET, suggest that distributed interactive simulation should be effective for combat training of armor forces. Compared to large-scale field exercises, DIS will obviously provide large cost savings as well as permit joint training that cannot be accomplished in any other way because of the prohibitive costs of exercises (including transportation, ammunition, and damage to equipment and the environment). If distributed simulation is used to test tactics for use in combat, or in preparing troops for actual combat, it can avoid public attention and protect planning and security. Confirmation of early estimates of the potential effectiveness and cost of distributed interactive simulation should be a high priority requirement, particularly as it applies to joint training and readiness. The investment in simulation, with its array of applications and potential contributions to

readiness, appears to be modest in comparison to the annual investment in weapon system modernization.

There could well be cases where simulation is found to be ineffective or too costly for training or both. In such cases, simulation should not be used for training. This could happen for a variety of understandable reasons. Those due to optimistic expectations of technological feasibility or cost are obvious. A less obvious reason is that reasonable training plans and effective integration of simulators into training programs in ways that are acceptable to a unit and its command are required to assure the proper and successful use of a simulator. Information presented in Chapter IV clearly shows that user acceptance and the existence of training plans are central to the successful use of simulators; simulators that are reported to have problems often lack training plans. Most other reported limitations of simulators are attributed to their not having features now considered desirable by users. Most of these are the result, variously, of outmoded equipment, desired upgrades, or insufficient quantities of equipment. Few of these problems present requirements for new technology; rather, they are the result of policy judgments made not to provide funds needed for upgraded or replacement equipment.

One may question the rationale that says simulators should be acquired if they train as well as actual equipment but cost less to own or use. This guideline is used to justify the current acquisition of simulators and we believe that it should be reconsidered. Remember that new weapon systems are acquired in order to provide performance superior to that of current equipment, in order quickly to overcome a potential enemy, and to minimize friendly casualties. Applying the same rule to the acquisition of new training equipment should lead us to prefer increased training effectiveness at the same (or less) cost than that of current equipment rather than equal effectiveness at less cost. Increased effectiveness of training equipment at increased cost may also make sense, as it does for weapons, provided that the increase in effectiveness has military value.

There are several ways to increase the effectiveness of a training simulator: devise training lessons more relevant to combat requirements, spend more time in training, develop prompt and accurate feedback to help students identify error-producing behavior, and reinforce correct responses; better hardware may also help. All simulators incorporate computers, and adding capabilities that enhance learning, such as those noted here, is well within the state-of-the-art. Given the capability of computer-based equipment to provide learning opportunities superior to those available in field training (e.g., critical events in combat scenarios, objective measurement, quick feedback, accurate diagnosis of

performance, and informed suggestions for improvement) there is every reason to believe that advanced distributed simulation can provide highly effective unit training. It cannot replace field exercises. The development of training strategies to improve the utility of distributed interactive simulation is a proper and realistic goal for research and development on military training.

Two types of efforts are envisaged: research on and development of training strategies for DIS, and specific application and tests of these strategies in CCTT, STOW, MDT2, and National Guard Training, that is, the new DIS systems now under development. Though these systems share many common technical features, they differ both in purpose of use and, as a consequence, in details of design. It is important to note that the major emphasis in R&D on methods of training is still given to individual training, and, of that, largely to training in institutions and not to on-the-job training, i.e., training in units. If research and development on collective training has not been neglected, it has surely received insufficient attention. Training for combat readiness places a priority on collective, rather than on individual, training.

The development of Distributed Interactive Simulation (also called Advanced Distributed Simulation) systems that will be used for Service and joint training is so heavily dependent on new technology in such areas as networking, semi-automated forces, and dynamic terrain and environment that consideration of how best to use DIS for training has fallen behind. Service experience with simulators (reported in Chapter IV) clearly shows that inadequate or non-existent training plans have seriously impaired the utility of current simulations and some future history may include DIS unless we act soon to develop training plans for their use. Note that twice as many funds are being spent now for R&D on training equipment than on training procedures; this is also the pattern for the Multi-Service Distributed Training Testbed (MDT2) and perhaps (we speculate) for CCTT and STOW. In 1984, the Air Force issued guidance to "develop system training plans for simulators" (Simulation Broad Area Review, 1984); in 1993, the Air Force Four-Star Flight Simulator Review found that "most weapon systems do not have system training plans."

Well before SIMNET was started, Col Jack Thorpe, USAF (Ret.) who led the development of SIMNET, wrote in a paper on visual systems for flight simulators:

> There is evidence to suggest that how a training device is used often accounts for more training output (efficiency, as well as effectiveness) than the hardware characteristics of the device. Sophisticated hardware refinements of a device might result in only token increases in training

effectiveness, whereas simple innovations in the use of the device might substantially increase its effectiveness. (Thorpe, Varney et al., 1978)

This is also the major theme developed by Lt. Gen. Frederic J. Brown, USA (Retired), with his emphasis on the need for training development to structure "... the training process to ensure that specific training events occur in the manner and sequence desired to achieve intended task training purposes" (Brown, 1993). Research and development on training strategies has, up to now, been focused on individual training, with much less attention given to crew and unit training. This is hard to understand or to explain since effectiveness in combat depends on crew and unit training for which individual training is a necessary but insufficient condition for success. R&D on unit training and on performance measurement of units in combat exercises and in command centers must clearly be given a much higher priority than it has at present. The issue of performance measurement of joint readiness, the product of training, to supplement commander's estimates of readiness, is now being addressed by The Joint Staff.

R&D on unit training will not be enough to ensure warfighting effectiveness since each Service is responsible for its own component training and not for Joint training. However, actual combat occurs as a joint, rather than exclusively a Service, activity. Some Service R&D now underway could contribute significantly to joint training; this includes Army work on Battle Command Staff Training, the Unit Performance Measurement System and analyses of exercises at the National Training Center, Navy work on Tactical Decision Making under Stress, and Air Force efforts on MultiRAD program.

The Multi-Service Distributed Training Testbed (MDT2) program is the only multi-service R&D program known to us that considers joint training; STOW may do so in the future. MDT2 is a testbed that is being built and whose functions must be tested to see if they will work as intended; it will use a close air support scenario for the initial demonstration of its feasibility. The use of MDT2 for research and development on training technology for joint combat will not start before FY 1995, at a level estimated to be about $2 million per year. Given the importance of joint training for joint readiness, this multi-Service program should be strongly supported and enhanced almost immediately so that serious attention can be given to development and test of joint training strategies for such missions as joint air defense, joint amphibious and land assault, and joint close air support (which will be demonstrated but not developed in the current effort). Work with MDT2 on joint training readiness should obviously be coordinated with the Army's CCTT and AVCATT programs and with ARPA's efforts on STOW and National Guard training.

DMSO, ARPA, and DMDC/TREAD, rather than the Services, appear to be the only OSD agencies that, with support by CJCS and the CINCs, are in a position to sponsor and support R&D on training strategies for joint combat missions.

Under the best of circumstances, it will be difficult to compare the effectiveness of DIS systems for training with that of actual equipment, i.e., in field exercises at Service and Joint levels on instrumented ranges. Here, we are again concerned with how best to evaluate the effectiveness of DIS training with, e.g., BFTT, TCTS, JACTS, MDT2, CCTT, STOW, and the National Guard system. All of these systems are intended to support combat training exercises and a key problem will be the availability of troops, commanders, and the personnel needed to conduct tests to determine training effectiveness and, later, to estimate joint training readiness. The need to engage relatively large forces both in DIS and in live exercises, in order to compare the effectiveness of each, means that such opportunities will be few and perhaps not sufficient to provide credible test data. Advantage should be taken of the opportunity to collect training effectiveness data in many scheduled exercises on a not-to-interfere basis for use in a joint training performance data base, perhaps as an extension to the Joint Universal Lessons Learned System (JULLS). At present, JULLS provides descriptive narrative information about exercises rather than objective performance measurement data.

This means, necessarily, that attention must also be given to the planning and conduct of tests meant to evaluate the effectiveness of training in DIS systems. There is a need to collect performance data on unit training wherever it may occur and to develop a database that could yield reliable data on unit training from independent events that were not planned to be part of a single, systematic, large-scale experiment. Consideration should be given soon to this possibility. Attention should also be given to holding a workshop and establishing special interest groups to encourage the exchange of information and coordination of activities on such topics as training strategies for unit and joint training, data bases to support meta-analyses of unit training, and design of DIS systems to improve the effectiveness of these simulations for training.

Discrepancies observed with currently used simulations are largely the result of aging, i.e., in contrast to what current technology advances could now make available and of constraints when they were procured or of decisions not to upgrade them now. A major limitation in some simulations is the absence of adequate training plans, despite guidelines that such plans are needed to insure proper use of a simulation and its integration in the

overall training plan. This is a management rather than a technological issue and has existed for the past 15 to 20 years.

Although this paper is directed primarily towards the capabilities and effectiveness of simulation technology for training, it is inappropriate to disregard the issue of cost. Money is never an unlimited asset and resources allocated to one type of training or training technology implies that fewer resources can be allocated to some other aspect of training technology. In the real world, policy with respect to how to train (e.g., in schools or on-the-job) or what type of R&D to promote (e.g., individual or collective training), or what type of training equipment to develop and procure is expressed ultimately as a series of budget decisions. Thus, it is naive to believe that information about training methods and equipment or about their effectiveness can be useful without parallel information about the cost of acquiring and using these methods of training. Therefore, it seems necessary to observe that only limited and insufficient attention has been given to the cost and effectiveness of various types of simulation relevant to training and that meaningful policy on R&D, acquisition, and training itself is thereby constrained. Prime areas that need better cost data, as well as effectiveness data, are those that clearly have high costs: these appear to be aviation training and training using distributed interactive simulation, because of its significance for joint readiness; the proper mix of school and on-the-job training is another key area.

There is nothing inherently difficult about collecting cost data on matters related to simulation and training, except perhaps generating a desire to do so. Such an effort could proceed in two phases: (1) defining the relevant cost elements of interest and (2) examining the appropriation accounts that provide the specified funds. In the case of individual training, for example, the cost elements of interest include pay and allowances of students while they are being trained, pay and allowances of military and civilian personnel who provide and support training, base operating costs of the training establishment, investment costs for instruction and procurement related to training, and the overhead costs for administration and command of the training agency (MMTR FY 1995, 1994, p. 80). The amounts of funds allocated to these cost elements are found in the following Appropriation Accounts: Operation and Maintenance, Military Personnel, Reserve Personnel, National Guard Personnel, Aircraft Procurement, Missile Procurement, Weapons Procurement, Other Procurement, Military Construction, and Research and Development. The Services use various combinations of these appropriations to support individual training (MMTR FY 1995, 1994, Appendix D).

Obviously, other cost elements and appropriation accounts apply to OPTEMPO, collective training, procurement, and research and development related to training. Except for individual training in institutions, there is no regular compilation of data on the costs of individual training in units, collective training in institutions or in units, OPTEMPO, or of various types of simulation for training. The regular reporting of training-related cost data makes it possible to identify trends that may have significance for readiness while contributing, at the same time, to the correction and refinement of the data that are being reported.

Skepticism about the value of simulators for training—regardless of their actual merit—is an understandable response to the threat that simulators pose to OPTEMPO. A standard remark is that "no pilot joined the Services so that he could fly in a box." Simulators pose a real threat to OPTEMPO because the cost of buying and using simulators can be balanced by a reduction in funds for flying hours, vehicle miles, or steaming hours per year. If not universal, resistance to the use of simulators is most pronounced among aviators of all Services, led by fighter pilots, with middling acceptance of simulators by transport pilots. There appears to be little resistance to the use of simulators for training armor forces in the Army, where the cost of the Close Combat Tactical Trainer (about $2 billion) will be offset by a reduction in funds for vehicle miles over the life of the CCTT (Noble and Johnson, 1991). Command post exercises are an accepted method of training at all levels in all Services: component, multi-Service, joint, and coalition. Such exercises take place ("on-the-job") in actual command centers in units, as well as in gaming centers in institutions; only the combat models used in such exercises may be challenged (but not often enough: see Davis and Blumenthal, 1991). Overall, we may observe that simulators and simulations are tools for training and for assessing readiness. They have various strengths and limitations for various types of applications. Assuring that the significant limitations of simulation and modeling are understood, the significant issue is to determine the optimum combinations of simulation and actual equipment that can provide the most effective training at the least cost, as appropriate for various types of training, up to the joint level. That would be a worthy goal.

The paradigm that identifies "who is trained" and "where training occurs" is a useful and easily understood tool for assessing what is known about the effectiveness and cost of all types of military training in the environments in which training takes place. Training occurs throughout a persons' military career, and in various places and environments. This perspective has helped us note that less is known than is desirable,

about the cost and effectiveness of on-the-job training (i.e., training that occurs in a non-training environment) or about the cost of collective training, in institutions as well as in operational units. We believe that the same paradigm has utility for developing budget data useful for developing policy on expenditures for RDT&E, procurement and utilization (operation and maintenance) of training at individual, unit, and joint levels.

VIII. FINDINGS AND RECOMMENDATIONS

This paper considers issues with respect to research and development, procurement and utilization that are central to the development of policy concerning the use of simulation for military training. Findings and Recommendations focus on budgets related to simulation and training, the cost and effectiveness of simulation, experience of the Services with simulation, distributed interactive simulation, and the technologies relevant to simulation and training.

FINDINGS

Budgets Related to Simulation and Training

Budget data on the costs of simulation and training are not reported regularly in the Department of Defense. This means that our ability to discern trends in costs of different types of training (e.g., individual or collective training), or to compare the costs of training at a school to training in an operational unit, or to direct research and development towards areas of highest pay-off for training effectiveness and cost is seriously limited. The costs of OPTEMPO are not well known; in fact, we found two different estimates of the costs of OPTEMPO that differ by a factor of 2.3. In this report, data from various sources are compiled to estimate what some of these costs are; some of the data are highly reliable, while some lack clear definition as to what cost elements may or may not be included. Our findings are summarized in Figure VIII-1.

Individual training occurs at schools and cost $14.4 billion in FY 94. Collective training occurs in operational units but its costs are not reported regularly; it was estimated to cost $12.7 billion in FY 93. Two estimates were found for expenditures for OPTEMPO (fuel, consumables, repairs and maintenance for flying hours, steaming days, and vehicle miles): $9.4 billion (FY 1993, LMI) and $21.4 billion (FY 1991, Angier, Alluisi and Horowitz). The larger estimate includes costs for repair and depot maintenance not included in the smaller estimate; except for this item, we were not able to resolve the basis for these widely different estimates. The fact that two FFRDCs developed such different estimates for the cost of OPTEMPO illustrates the importance of having reliable and regular estimates of the costs associated with various aspects of simulation and training.

Type of Expenditure	Amount[1]	Period	Source
RDT&E			
Simulators for weapon systems	$0.336	FY91–97	Frost & Sullivan (1993)[2]
Technology			
Training equipment	0.101	FY94	MATRIS (1993)[3]
Training methods	0.038	FY94	MATRIS (1993)[3]
Modeling and simulation			
Joint commands	0.019	FY 91–92	IG (1993)[4]
DMSO	0.073	FY 93–94	DMSO (1994)[5]
ARPA	0.103	FY 92–97	ARPA (1993)[6]
Initial investment			
Procurement of simulators		FY 91–97	Frost & Sullivan (1993)
Aviation $ 0.800			
Non-system devices 0.243			
All others 0.057			
	1.100		
Models and simulations	NA		
Military Construction	NA		
Operating and Support			
Individual training in institutions	14.4	FY94	MMTR (1993)[7]
Individual training in units	NA		
Collective training in institutions	NA		
Collective training in units	12.7	FY93	LMI (1993)[8]
OPTEMPO	9.4	FY93	LMI (1993)
	21.4	FY91	Angier et al. (1992)[9]
Joint exercises	0.425	FY 94	Briefing material
Simulator maintenance	0.369	FY 91–97	Frost & Sullivan (1993)

1 Amount, in billions, for year cited or average of years noted.
2 Frost & Sullivan (1993).
3 Manpower and Training Research Information System (1993).
4 Inspector General (1993).
5 Defense Modeling and Simulation Office (1994).
6 Advanced Research Projects Agency (1993).
7 Military Manpower Training Report, FY 94 (1993).
8 Logistics Management Institute (1993).
9 Angier, Alluisi, and Horowitz (1992).
NA: Not Available

Figure VIII-1. Estimated Annual Expenditures for Training and Simulation, in Terms of RDT&E, Initial Investment, and Operating and Support of Training

The procurement of simulators for training costs about $1.1 billion per year (average of FY 91–97); RDT&E and support of simulators cost an additional $0.5 and $0.4 billion, respectively. The most expensive simulators are for aviation; they cost about $0.8 billion per year to procure (73 percent of the costs of simulators for all types of weapon systems); non-system training devices cost $0.2 billion (22 percent); simulators for all other types of weapons cost $0.6 billion per year (5 percent).

Expenditures for RDT&E on simulators and training equipment average about $0.4 billion per year, training methods about $0.04 billion, and modeling and simulation (for DMSO, ARPA, and the Joint commands) about $0.19 billion per year.

A significant issue in the cost of training concerns who is trained and where training occurs. "Who is trained" refers to individual and collective training; "Where training occurs" refers to training at institutions (i.e., schools) or in the operational units. The problem in ascertaining the cost of each type of training at various places (and the related issue of evaluating their cost and effectiveness) arises because, except for individual training at institutions, there is no regular or consistent report that identifies the cost of all other types of training. Our estimates of what these costs are were compiled from a variety of sources, as shown in Figure VIII-2. The costs of RDT&E and initial investment are not included in this figure; we were not able to find any usable data on the costs of collective training in institutions or of individual training in units. We estimate individual training in institutions to cost $14.4 billion in FY 94; this is a reliable figure. Other costs, that are estimates by a variety of sources, are: collective training in units cost $12.7 billion in FY 1993, OPTEMPO cost either $9.4 or $21.4 billion (FY 91), according to two different estimates; and joint exercises cost about $0.425 billion (FY 1994).

Providing reliable, consistent, and regularly updated data on the actual costs of individual and collective training at institutions and units is a matter of the utmost urgency, since these expenditures directly influence the readiness of our troops.

Cost and Effectiveness of Simulation

Evaluations of the cost and effectiveness of simulation for training are based almost exclusively on the use of flight and maintenance simulators and of computer-based instruction for initial, individual training at institutions. The cost and effectiveness of simulation for more advanced individual training in units or for collective training at institutions or in units for component or joint training has not received much attention.

Where Training Occurs

Who is trained	Institution	Unit
Individual	By service, FY 94[1] Army $5.4 B Navy 4.5 Marine Corps 1.3 Air Force 3.2 14.4 By type, FY 94[1] Recruit $1.2 B Officer acquisition .5 Specialized skill 4.1 Flight 2.2 Professional development .9 One station (Army) .3 14.4	Not available: Individual (on-the-job) training in units for those trained only on the job, job familiarization for those trained at schools, and training for those assigned jobs that do not match their MOS[6]
Collective	Army Combat Training Centers, FY 95 .5 B[5] Other data not available	Unit training $12.7 FY 93[2] OPTEMPO 9.4 FY 93[2] 21.4 FY 91[3] Joint exercises 0.425 FY 94[4]

1 MMTR (1993).
2 LMI (1993).
3 Angier, Alluisi, and Horowitz (1992).
4 Briefing Estimate.
5 AUSA (1994); about one-third of this total is for transport to and from the training center (Fig. II-16).
6 CBO (1994) estimates 6-10 percent mismatch between job and MOS in the Army, FY 1993 (p. 32).

Figure VIII-2. Estimated Annual Expenditures for Training, by Type of Training, and Where Training Occurs (does not include RDT&E and initial investment)

The available findings show that simulators are cost-effective for initial flight and maintenance training in institutions: they train as well as does actual equipment and cost less to procure and use. This finding applies also to computer-based instruction, in comparison to conventional classroom instruction. Simulators are a good investment. The cost of their procurement can be amortized in periods of one to four years. However, optimum combinations for the use of simulators and actual equipment for various types of

training have not been studied; nor have such critical issues as the rates of learning and forgetting, which are basic to determining how much and when simulators or actual equipment are best used for initial and refresher training. The decision to use new simulators on the basis of equal effectiveness and less cost than actual equipment, the rule used at present, overlooks the fact that, for military purposes, one should seek simulators that provide increased performance effectiveness at the same or lesser cost.

Service Experience with Simulation

Information was collected on over 50 simulations considered by the four military services to be successful or to have problems. Features associated with successful simulations are high-user acceptance, timely availability of a well-developed training plan to show how the simulator should be used, genuine contribution of the simulator to training demonstrated by features for performance measurement and feedback, acceptable costs, and minimum interference by simulators with existing norms for training with actual equipment, i.e., little reduction in budgets for flying hours, vehicle miles, and steaming hours. Problems with existing simulations are attributed to inadequate or non-existent training plans, discrepancies between the performance of simulators and actual equipment, and the absence of features considered to be important for training, e.g., motion platforms, sensors (IR, radar, EW), feedback capability. Almost all of these limitations are the result of decisions, for cost or other reasons, to procure simulations with limited or no capability for training on certain tasks. Current technology appears adequate to deal with most of the deficiencies that were reported, provided that there is an interest in and funds are appropriated to upgrade and improve current equipment.

The following trends are observable with respect to the role of simulators for training: (1) a reduction of flying hours for training, up to 50 percent per year for transport aircraft, and of vehicle miles per year for armor, to pay for the cost of procuring a new distributed training system for close combat; (2) use of simulators to complement flight training for advanced combat aircraft, with a slight reduction in flying hours; and (3) the development of low-cost, unit-training devices to be placed at most flight bases for use as modifiable, part-task trainer for, e.g., electronic warfare, target recognition, and digital terrain land mass training. Current flight simulators will be phased out because they are too expensive to be placed at all flight bases. A significant trend is the development and use of advanced distributed simulators in all Services for collective, combat training but it is too soon to assess their utility for training.

Distributed Interactive Simulation

Distributed Interactive Simulation (DIS) systems now being developed have a great potential for improving unit and joint training and joint readiness (and will also have important applications in other areas, such as test and evaluation, tactics and doctrine, and mission rehearsal). However, the development of training strategies, i.e., ways to use DIS systems to improve collective training, is lagging behind development of the underlying technology in hardware and software, communications and standards needed to support DIS. A problem that will surely arise is how best to use these systems for training (and test and evaluation) and how to evaluate their effectiveness and cost. Meaningful tests will require large numbers of people to serve as test subjects over extended periods of time, as well as scenarios and performance measuring techniques that must still be developed and tested in order to be available when needed; this also applies to the training of personnel to design and conduct tests and collect reliable test data needed to evaluate the utility of DIS for training and to support a decision to procure the required equipment.

Technologies Relevant to Simulation and Training

A review of technologies critical to simulation and training included R&D on distributed interactive simulation in areas concerned with networks, semi-automated forces, terrain and environment, range instrumentation, individual combatants, virtual environments, and training technology. Areas that receive major funding ($100 million a year or more) are networks, terrain and environment, and range instrumentation. Within these areas, increased attention should be given to develop the Asynchronous Transfer Mode (ATM) protocol for DIS, support for exercise management, compatibility between data bases for terrain and environment, radio-frequency network bandwidths for range instrumentation, and communication standards. Less support is being given to methods of training, design, and use of individual combatants in DIS and SAFOR. There is a need for methods of evaluating performance in all areas, clarification of appropriate representations of individual combatants (including dual-use potential) in DIS, and effective ways to use and measure the training potential of most DIS systems.

RECOMMENDATIONS

Priorities for Research and Development

Review the research and development programs on simulation and training to assure that they focus on areas of highest expenditures and greatest potential payoff. These

areas are aviation simulators, aviation training, OPTEMPO, joint training and readiness, and distributed interactive simulation.

Distributed Interactive Simulation

Extend efforts to evaluate the cost and effectiveness of training technology beyond the limited areas of flight and maintenance simulators and computer-based instruction. Attention should be given to methods of evaluating the cost and effectiveness of distributed interactive simulation systems, such as the Close Combat Tactical Trainer (CCTT), Synthetic Theater of War (STOW), and the Multi-Service Training Testbed (MDT2), and to the use of modeling for joint training, where the major issues are likely to be validity and effectiveness.

Training Strategies

Give high priority to the development and evaluation of training strategies for the use of distributed interactive simulation for large-scale Service training and joint training for readiness. Emphasize efforts concerned with estimating performance in Joint training exercises because this will provide a way to estimate joint training readiness. Development and evaluation of methods of measuring performance in joint training should be started soon in order to be in place when needed to evaluate the new DIS systems, as they become available in three to five years.

Performance Data Base

Develop a data base system that provides a systematic way to compile performance data that become available from large-scale Service and joint exercises. Evaluating the effectiveness of new DIS systems for training (e.g., CATT, MDT2, and STOW) will be difficult because of the large resources needed for test subjects (military personnel for extended exercises), data collection, and personnel qualified to conduct tests and analyze results. The reason to develop a comprehensive data base is that it can provide a means to determine lessons learned from many different tests to supplement the large-scale test programs that will be expensive and difficult to conduct.

How Much Training Is Enough

Support research and development on key issues of how much training is enough and how often refresher training must occur to maintain joint training readiness. There is a

significant absence of critical information on training with respect to learning and forgetting curves and on developing optimum combinations of the use of simulators and actual equipment for various applications. This must be remedied in order to maximize the benefits available from investments in different equipment and methods of training.

Combat Models

Insufficient attention has been paid to the use and effectiveness of models used for joint and large-scale Service training. A program to evaluate the verification, validity, and accreditation of models used in unit, battle command staff, and joint training should be undertaken.

Cost-Effectiveness Paradigm

The utility of simulations has generally been decided on the basis of equal effectiveness and less cost than the use of actual equipment. Although this is an acceptable guideline, attention should be directed towards the development of simulations that increase performance effectiveness at no appreciable increase in cost or at lesser cost. Military effectiveness benefits from training for *improved* performance rather than merely to equal current levels of proficiency.

Cost Data on Training

Except for data furnished to Congress on individual training in institutions, there is a notable absence of regularly reported data on the costs of collective training in institutions and operational units, on the costs of OPTEMPO, exercises, on-the-job training, joint training, and on the acquisition of training-related hardware and software. Undertake the development of cost-reporting systems that will identify, define, and make regularly available cost data on training needed to support policy decisions in each of these areas.

On-the-Job Training

Only limited attention has been given to the cost and effectiveness of on-the-job training, in comparison to formal training in institutions. Review current R&D activities in order to plan a more vigorous R&D effort toward on-the-job training. New developments in computer-based instruction, distance learning, and portable, miniaturized electronic job aids make this an attractive area to improve the effectiveness and reduce the costs (largely hidden) of on-the-job training.

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APPENDIX A

ABBREVIATIONS

ABBREVIATIONS

A/AMTS	Avionics/Armament Maintenance Trainer System
AAMRL	Armstrong Aerospace Medical Research Laboratory
AARS	After Action Review System
ACC	Air Combat Command
ACM	Air Combat Maneuvering
ACMI	Air Combat Maneuvering Instrumentation
ADF	Air Defense Fighter
ADS	Advanced Distributed Simulation
AETC	Air Education and Training Command
AFRES	Air Force Reserve
AFSOF	Air Force Special Operations Force
AFSPACECOM	Air Force Space Command
AFT	Avionics Familiarization Trainer
AGES II	Air-Ground Engagement System II
AGPT	Ausbildungsegerat Gefechtssimulator Panzer Truppe
AI	Artificial Intelligence
AIS	Aircraft Instrumentation System
AITST	Army Integrated Thermal Signature Target
ALSA	Air Land Sea Agency
ANG	Air National Guard
ARPA	Advanced Research Projects Agency
ARPTT	Aerial Refueling Part Task Trainer
ASC	Aeronautical Systems Center
AB	Army Science Board
ARTEP	Army Training Evaluation Program
ASD (FM&P)	Assistant Secretary of Defense (Force Management and Personnel)
ATCCS	Army Tactical Command and Control System

ATD	Aircrew Training Device
ATF	Advanced Tactical Fighter
ATM	Asynchronous Transfer Mode
ATP	Acceptance Test Plan
ATS	Aircrew Training System
AWSIM	Air Warfare Simulation
BBS	Brigade/Battalion Battle Simulation
BCTP	Battle Command Training Program
BFIT	Battle Force In-Port Training
BFTT	Battle Force Tactical Training
BOPTT	Boom Operator Part Task Trainer
C/SCSC	Cost/Schedule Control Systems Criteria
CADIS	Communication Architecture for Distributed Interactive Simulation
CAF	Combat Air Forces
CAI	Computer-Aided Instruction
CAT	Canadian Armor Trophy
CATS	Combined Arms Training Strategy
CATT	Combined Arms Tactical Trainer
CBI	Computer-Based Instruction
CBITS	Computer-Based Instruction Training System
CBS	Corps Battle Simulation
CBT	Computer-Based Training
CCTS	Combat Crew Training Squadron
CCTT	Close Combat Tactical Trainer
CDR	Critical Design Review
CLS	Contractor Logistics Support
CMI	Computer Managed Instruction
CMSS	Counterdrug Modeling and Simulation System
COFT	Conduct of Fire Trainer
CPAF	Cost Plus Award Fee

CPT	Cockpit Procedures Trainer
CS	Combat Support
CSRL	Common Strategic Rotary Launcher
CSS	Combat Service Support
CTC	Combat Training Center
CTS	Control and Tracking System
DBS	Doppler Beam Sharpening
DBTS	Data Base Transformation System
DBWS	Data Base Sork Station
DDS	Display and Debriefing System
DD250	Material Inspection and Receiving Report
Dem/Val	Demonstration/Validation
DFAD	Digital Feature Analysis Data
DIIN	Defense Information Infrastructure Network
DIS	Distributed Interactive Simulation
DISA	Defense Information Systems Agency
DMA	Defense Mapping Agency
DMSO	Defense Modeling and Simulation Office
DoD	Department of Defense
DRFP	Draft Request For Proposals
DRLMS	Digital Radar Landmass Simulation
DSB	Defense Science Board
DTED	Digital Terrain and Elevation Data
EAF	Egyptian Air Force
EC	Electronic Combat
ECM	Electronic Counter Measure
ECP	Engineering Change Proposal
EMD	Engineering and Manufacturing Development
ENJJPT	Euro-NATO Joint Jet Pilot Training
ENWGS	Enhanced Naval Wargaming System

EPAFs	European Participating Air Forces
EPG	European Participating Government
EPTM	ENJJPT Procedures Trainer Modernization
ESIG	Evans and Sutherland Image Generator
EW	Electronic Warfare
EWO	Electronic Warfare Officer
FAA	Federal Aviation Administration
FCA	Functional Configuration Audit
FCSMT	Flight Control System Maintenance Trainer
FEA	Front End Analysis
FMS	Foreign Military Sales
FOC	Full Operational Capability
FOT&E	Follow-On Operational Test and Evaluation
FRS	Fleet Readiness Squadron
FSC	Field Service Center
FSCATT	Fire Support Combined Arms Tactical Trainer
FSD	Full Scale Development
GFE	Government Furnished Equipment
H/SI	Hardware/Software Integration
I/SWG	Industry/Service Working Group
IDRLMS	Improved Digital Radar Landmass Simulation
IEWTD	Improved Electronic Warfare Training Device
IOC	Initial Operating Capability
IOS	Instructor Operator Station
IR	Infrared
ISD	Instructional Systems Design
IST	Integrated Systems Trainer
IVIS	InterVehicular Information System
JSFTS	Joint STARS Flight Training System
JARM	Jammer, Artillery, Radar, Missile

JCM	Joint Conflict Model (new version of Janus)
JCS	Joint Chiefs of Staff
JPO	Joint Program Office
JSORD	Joint System Operational Requirements Document
JSTARS	Joint Surveillance Target Attack Radar System
kps	kilobytes per second
LANTIRN	Low Altitude Navigation and Targeting Infrared System for Night
LBO	Launch Base Operations
LFOV	Limited Field of View
LGT	Landing Gear Trainer
LMI	Logistics Management Institute
LPTT	LANTIRN Part Task Trainer
MAC	Military Airlift Command
MAD	Magnetic Anamoly Detector
MDT2	Multi-service Distributed Training Testbed
MLU	Mid Life Upgrade
MMTR	Military Manpower Training Report
MOB	Main Operating Base
MPTS	Manpower, Personnel, Training and Safety
MRD	Mission Rehearsal Devices
MSIP	Multi-Stage Improvement Program
MST	Maintenance Skills Tutor
MT	Mission Trainer
MTD	Maintenance Training Device
MTE	Maintenance Training Equipment
NDRLMS	New Digital Radar Landmass Simulation
NTC	National Training Center
NWC	Naval War College
OAS	Offensive Avionics Stations
OBT	On-Board Trainer

OCU	Operational Capabilities Upgrade
OFP	Operational Flight Program
OFT	Operational Flight Trainer
OJT	On-the-Job Training
O&M	Operations and Maintenance
OM&S	Operations Management and Support
OMAR	Objectives and Media Analysis Report
OPTEMPO	Operating Tempo
OSMT	Offensive Station Mission Trainer
OSS	Offensive Station Simulator
P&A	Price and Availability
PE	Program Element
PCA	Physical Configuration Audit
PDR	Preliminary Design Review
PDU	Protocol Data Unit
PGS	Precision Gunnery Simulator
PMRT	Program Management Responsibility Transfer
POM	Program Objective Memorandum
P/S	Primary/Secondary
PTT	Part Task Trainer
PVI	Pilot Vehicle Interface
R&D	Research and Development
RAA	Required Assets Available
RDT&E	Research, Development, Test and Evaluation
REFORGER	Return of Forces to Germany
RESA	Research, Evaluation and Systems Analysis (Navy Simulation)
RFI	Request for Information
RFP	Request for Proposal
RFT	Ready for Training
RFU	Ready for Use

RI	Range Instrumentation
RWR	Radar Warning Receiver
SAC	Strategic Air Command
SAF	Secretary of the Air Force
SAR	Synthetic Aperture Radar
SCU	Software Capabilities Upgrade
SDA	Simulator Development Activities
SDIP	Simulator Data Integrity Program
SECT	Simulator for Electronic Combat Training
SFT	Systems Familiarization Trainer
SIMNET	Simulator Networking
SMTS	Simulated Maintenance Trainer System
SNS	Satellite Navigation Station
SOF	Safety of Flight
SON	Statement of Need
SOS	Special Operations Simulation
SRR	System Requirements Review
SSC	Software Support Center
SSDB	Standard Specification Data Base
STOW	Synthetic Theater of War
SUNT	Specialized Undergraduate Navigator Training
TAC	Tactical Air Command
TACTS	Tactical Air Combat Training System
TAF	Tactical Air Force
TASWIT	Tactical Advanced Simulated Warfare Integrated Trainer
TBD	To Be Determined
TC	To Complete
TCT	Total Contract Training
TCTS	Tactical Combat Training System
TEC	Training Extension Course

TFS	Trainer Flight Simulator
TIS	Tracking Instrumentation System
TMS	Training Management System
TRA	Training Requirements Analysis
TRAR	Training Requirements Analysis Reports
TREAD	Training and Readiness Evaluation Analysis Division
TSAR	Training System Analysis Report
TSBAR	Training System Basis Analysis Report
TSRA	Training Systems Requirement Analysis
TSRR	Training System Readiness Review
TSSC	Training System Support Center
TTNRT	Table-Top Navigational Rendezvous Trainer
TUAF	Turkish Air Force
TWGSS	Tank Weapons Gunnery Simulation System
UCOFT	Unit Conduct of Fire Trainer
UPT	Undergraduate Pilot Training
UQT	Unit Qualification Training
USAF	United States Air Force
USAFA	United States Air Force Academy
USAFE	United States Air Forces in Europe
UTD	Unit Training Device
UTSS	Universal Threat System for Simulators
VCASS	Visually Coupled Airborne Systems Simulator
VE	Virtual Environment
WAN	Wide Area Network
WARSIM	Warfighters' Simulation
WST	Weapon System Trainer

APPENDIX B

SERVICE RESEARCH AND DEVELOPMENT PROJECTS ON SIMULATION AND TRAINING, FY 1992–1995 (SOURCE: MATRIS, 1993)

Service Expenditures for R&D on Simulation and Training, FY 1992–1995 (Dollars in Millions)

	FY 92	FY 93	FY 94	FY 95	Total
Army	81.9	65.6	71.9	70.7	292.1
Navy	19.6	18.7	13.9	16.6	68.9
Air Force	53.9	54.8	53.2	59.9	222.2
Total	155.4	139.1	139.0	147.3	580.9

STRICOM Simulation Training and Intelligence Command
NTSC National Training Center (now Naval Air Warfare Center–Training Systems Division)
TSSSPO Training Simulation Systems Special Project Office
Source: Matris, 1993

Distribution of Funds to Training Equipment Development and Training R&D Agencies, FY 1993, by Service

	Training Equipment		Training R&D		Total
Army	STRICOM	$ 51.5 M	ARI	$ 14.1 M	$ 65.6 M
Navy	NTSC	16.6	NADC	2.1	18.7
Air Force	TSSSPO	32.6	AL/HRA	22.2	54.8
Total		100.7		38.4	139.1

STRICOM Simulation Training and Intelligence Command
NTSC National Training Center (now Naval Air Warfare Center–Training Systems Division)
TSSSPO Training Simulation Systems Special Project Office
Source: Matris, 1993

Service R&D Projects Dealing with Simulation and Training, FY 1992–1995, by Service (Dollars in Millions)

	Project Number[a]	FY 92	FY 93	FY 94	FY 95	Total
Army	A230	3.439	8.483	4.809	4.551	21.282
	A790-ST	3.769	0	0	0	3.769
	A790-HF	2.807	0	0	0	2.807
	A791-ET	3.962	4.273	8.688	10.59	27.513
	A791-MP	3.869	4.806	0.459	0	9.134
	A794	4.222	4.992	0	0	9.214
	DB39	2.838	2.561	4.423	4.563	14.385
	D241	27.816	16.952	48.207	46.041	139.016
	D396	5.752	2.547	5.292	5.000	18.591
	D275	0	6.336	0	0	6.336
	D574	23.442	14.617	0	0	38.059
	Total	81.916	65.567	71.878	70.745	290.106
Navy	RM33D40	1.751	1.845	1.053	1.065	5.714
	RM33T24	0.956	1.249	1.185	1.26	4.65
	RM33T25	0.3	2.645	1.889	2.645	7.479
	L1773	4.666	5.28	5.791	6.583	22.32
	R1889	0.5	2.5	4.0	5.0	12.0
	W2124	0.827	2.119	0	0	2.946
	S1427	10.646	3.1	0	0	13.746
	Total	19.646	18.738	13.918	16.553	68.885

[a] See list p. B-6 ff.

Source: MATRIS, 1993

Service R&D Projects Dealing with Simulation and Training, FY 1992–1995, by Service (Dollars in Millions) (continued)

	Project Number	FY 92	FY 93	FY 94	FY 95	Total
Air Force[a]	1123[a]	7.213	8.711	8.207	8.887	33.018
	2743[a]	7.896	5.927	8.172	8.608	34.265
	3257	4.452	4.517	3.69	3.8	18.388
	2325	7.088	3.6	3.9	4.179	18.838
	2769	8.981	8.525	2.6	2.3	22.406
	2851	4.285	3.6	2.6	1.5	11.985
	2901	5.91	3.7	0	0	9.61
	3000	0	0	2	1.5	3.5
	2968	0.4	0.62	0	0	1.02
	3282	0.67	1.1	0.7	0	2.47
	3772	3.561	0.805	0.6	0	4.966
	4022	2.589	10.674	8.762	1.7	23.725
	4033	0	0	7.142	22.707	29.849
	3818	0.828	3.046	4.85	4.8	13.524
	Total	53.873	54.825	53.223	59.981	222.202
All Services	**Total**	155.435	139.130	139.019	147.279	580.863

a As this paper was going to press, we were informed that these figures reported by MATRIS should be corrected as shown below. Please note that we were NOT able to make these corrections in the body of this report.

Project	FY 92	FY 93	FY 94	FY 95	Total
1123	6.139	7.225	5.856	6.754	25.974
2743	4.484	4.981	4.462	4.448	18.375
Overhead (civilian salaries,TDY, O&M)	2.058	2.241	1.744	1.744	7.757
TOTAL	12.651	14.447	12.062	12.946	52.106

Projects and Expenditures for R&D on Simulation and Training, FY 1993, by Service

I. Army

1. PE 0602727A, Project A230: Non-system training devices, STRICOM
Description: DIS improving and enabling research.
FY93: $8.483 M

2. PE 0602785A, Project A790-HF: Human performance effectiveness and simulation, ARI
Description: how to design simulators that fit people.
FY93: $0.00

3. PE 0602785A, Project A790-ST: Human performance effectiveness and simulation, ARI
Description: how to design simulators that fit people.
FY93: $0.00

4. PE 0602785A, Project A791-ET: Education and training technology, ARI
Description: how to design simulators that fit people.
FY93: $4.273M

5. PE 0602785A, Project A791-MP: Education and training technology, ARI
Description: research on best training methods with simulators
FY93: $4.806M

6. PE 0603007A, Project A794: Education and training, ARI
Description: methods for training enhancement
FY93: $4.992M

7. PE 0603003A, Project DB39: Flight Simulator Components, STRICOM
Description: DIS ATD
FY93: $2.561M

8. PE 0604715A, Project D241: Simulation and Training Devices, STRICOM
Description: enhanced technology in various simulators/simulations.
FY93: $16.952M

9. PE 0604715A, Project D396: Tactical Simulation, STRICOM
Description: enhanced simulations.
FY93: $2.547M

10. PE 0604810A, Project D275: Synthetic flight training systems, STRICOM
Description: technology enhancements in flight training.
FY93: $6.336M

11. PE 0604715A, Project D574: Combined Arms Tactical Trainer, STRICOM
Description: CCTT acquisition activity.
FY93: $14.617M

II. Navy

12. PE 0602233N, Project RM33D40: Tactical Decision Making under Stress (TADMUS), NTSC
Description: human performance study.
FY93: $1.845M

13. PE 0602233N, Project RM33T24: Simulation Technology, NTSC
Description: enhanced technology for training on various systems.
FY93: $1.249M

14. PE 0602233N, Project RM33T25: Virtual environment training technology, NTSC
Description: improved visual technology.
FY93: $2.645M

15. PE 0603707N, Project L1733: Simulation and training devices, NTSC
Description: various technology enhancements.
FY93: $5.280M

16. PE 0603792N, Project R1889: Carrier Based Weapon Systems Trainer (CV WST), NTSC
Description: new training tool.
FY93: $2.500M

17. PE 0604714N, Project W2124: Air Warfare Training Development, NADC
Description: new software.
FY93: $2.119M

18. PE 0604715N, Project S1427: Surface Tactical Team Trainer, NTSC
Description: soft and hardware for simulations.
FY93: $3.100M

III. Air Force

19. PE 0602205F, Project 1123: Aircrew Training Technology, AL/HRA
Description: methods for enhancd training.
FY93: $8.711M

20. PE 0603227F, Project 2743: Tactical Multi-ship Aircrew Training Research, AL/HRA
Description: find limits of DIS to tactical fighter air force.
FY93: $5.927M

21. PE 0604227F, Project 3257: Helmet-Mounted Technology, AL/HRA
Description: new visual tool.
FY93: $4.517M

22. PE 0604227F, Project 2325: Simulator Development Activity, Training Systems Special Projects Office
Description: hard and software developments.
FY93: $3.600M

23. PE 0604227F, Project 2769: Simulator Update Development/Simulator Requirements Definition, Training Systems Special Projects Office
Description: improvements of existing simulators.
FY93: $8.525M

24. PE 0604227F, Project 2851: Standard DoD simulator database/common transformation program, Training Sytems Special Project Office
Description: software standards.
FY93: $3.600M

25. PE 0604227F, Project 2901: B-1B Weapon Systems Trainer, Training Systems Special Projects Office
Description: weapons systems trainer.
FY93: $3.700M

26. PE 0604227F, Project 3000: KC-135 Aircrew training system.
Description: weapons systems trainer.
FY93: $0.000

27. PE 0604227F, Project 2968: Modular Simulator Design, Training Systems Special Projects Office
Description: software standardization.
FY93: $0.620M

28. PE 0604227F, Project 3282: C-17 Aircrew Training System, Training Systems Special Projects Office
Description: weapons systems trainer.
FY93: $1.100M

29. PE 0604227F, Project 3722: C-141 Aircrew Training System, Training Systems Special Projects Office
Description: weapons systems trainer.
FY93: $0.620M

30. PE 0604227F, Project 4022: Simulator for Electronic Combat Training (SECT), Training Systems Special Projects Office
Description: weapons systems trainer.
FY93: $10.674M

31. PE 0604227F, Project 4033: JPATS Training System, Training Systems Special Projects Office
Description: weapons systems trainer.
FY93: $0.000

32. PE 0604243F, Project 3818: Maintenance Skills Tutors (MST), AL/HRD
Description: weapons systems trainer.
FY93: $3.046M

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13. ABSTRACT ***(Maximum 180 words)***

All types of simulation are considered: stand-alone, networked interactive simulation, live exercises, and combat models. The utility of simulation is examined for individual and collective training conducted at institutions and in operational units. Cost data are reported on individual training at schools, training technology, collective training in units, operating tempo, and procurement of simulation. Simulators used for flight training and maintenance training are cost-effective, compared to the use of actual equipment; the same is true for computer-based instruction. The acceptance and use of simulators depends heavily on the existence of adequate training programs, adequate performance feed-back, ability to replicate actual operating conditions, and user acceptance by unit commanders. Distributed interactive simulation is expected to make a major improvement in collective and joint training but it is too early to assess its utility. Suggestions are made with regard to the development of cost data needed for establishing policy on the use of simulation for training as well as for the support of technology needed to improve collective and joint training and joint readiness.

14. SUBJECT TERMS

simulation, training, training costs, training effectiveness, cost-effectiveness, distributed interactive simulation, simulation technology

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